Volume 32 JULY, 1948 Number 7

# BULLETIN
## *of the*
# American Association *of* Petroleum Geologists

## CONTENTS


SOCIAL TRENDS IN SCIENCE — *BY CARROLL E. DOBBIN* — 1211

INTEGRATION IN EXPLORATION — *BY CECIL H. GREEN* — 1216

PETROLEUM IN EUROPEAN RECOVERY PROGRAM — *BY MAX W. BALL* — 1221

ARTESIAN SALT FORMATIONS — *BY BAILEY WILLIS* — 1227

CORRELATION OF SENTINEL BUTTE SHALE IN WESTERN NORTH DAKOTA — *BY ROLAND W. BROWN* — 1265

GEOLOGICAL OBSERVATIONS ON CURAÇAO, N. W. I. — *BY H. P. SCHAUB* — 1275

DESCRIPTION, CORRELATION, AND PALEOECOLOGY OF TERTIARY CIPERO MARL FORMATION, TRINIDAD, B. W. I. — *BY R. M. STAINFORTH* — 1292

ISOPACHOUS MAPS OF SAND RESERVOIRS — *BY JAY B. WHARTON, JR.* — 1331

SOME NOTES ON GEOLOGY AND GEOLOGISTS, 1907-1947 — *BY HUGH D. MISER* — 1340

GEOLOGICAL NOTES

Clarification of Upper Cambrian Stratigraphy in Oklahoma — *By E. A. Frederickson* — 1349

Summary of Oil Production from Fractured Rock Reservoirs in California — *By W. S. Eggleston* — 1352

RESEARCH NOTES

Survey of College Students Majoring in Geology — *By A. I. Levorsen* — 1356

REVIEWS AND NEW PUBLICATIONS

Structural Geology of Region between Mizil and Targovisti [Roumania], by N. Oncescu — *By Walter M. Small* — 1358

Guide to the Geology of Central Colorado, *Quarterly* of Colorado School of Mines — 1360

Recent Publications — 1360

ASSOCIATION ROUND TABLE

Nominating Committee — 1366

Membership Applications Approved for Publication — 1366

Regional Meeting, Pittsburgh, October 4-9, 1948 — 1375

Joint Annual Meeting, St. Louis, March 14-17, 1949 — 1376

Our National Responsibility as Geologists — *By A. I. Levorsen* — 1378

Remarks of New Honorary Member — *By Hugh D. Miser* — 1380

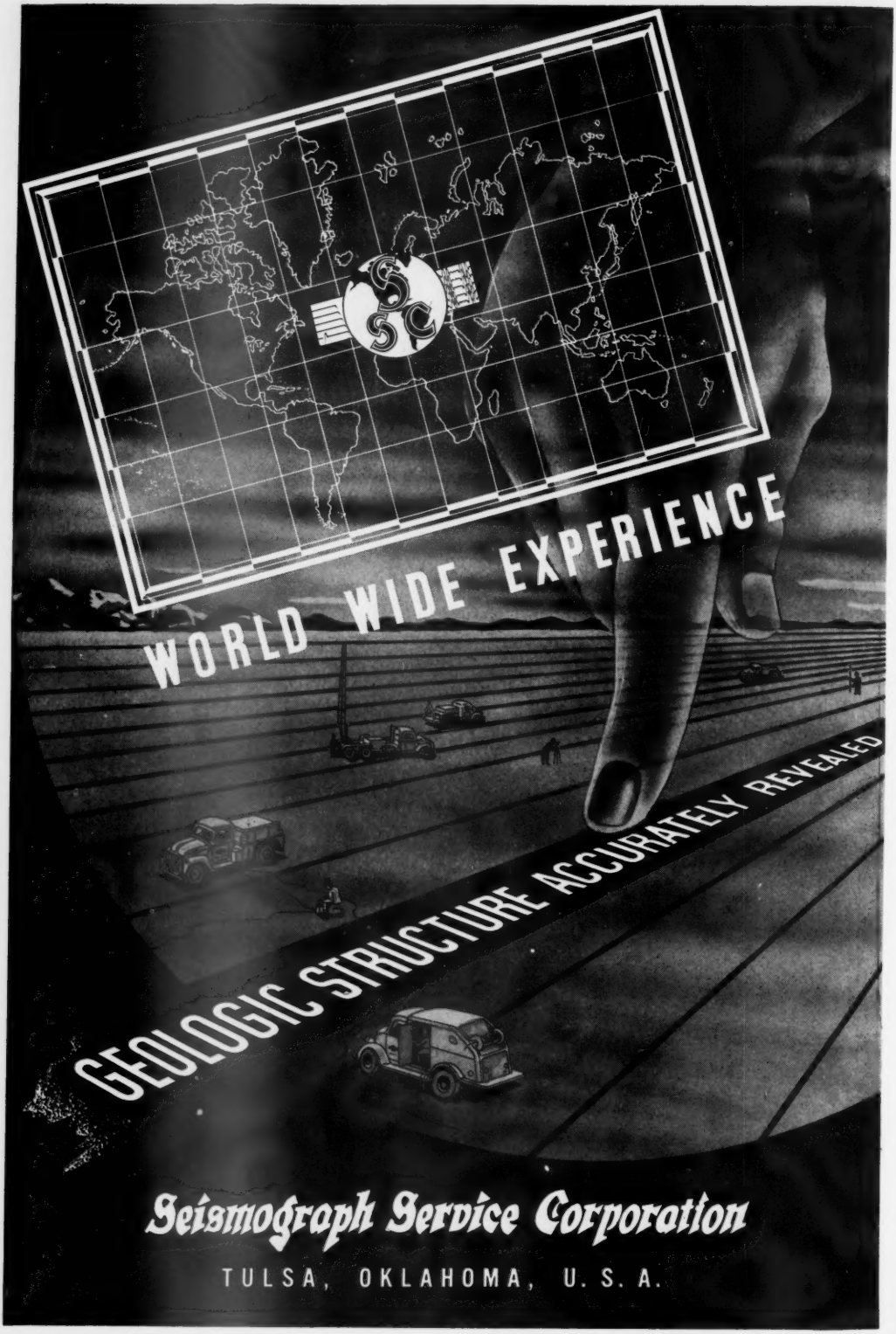
MEMORIAL

George Elmer Abernathy — *By John Mark Jewett* — 1382

AT HOME AND ABROAD

News of the Profession — 1385


COPYRIGHT 1948, BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.


WORLD WIDE EXPERIENCE
GEOLOGIC STRUCTURE ACCURATELY REVEALED
Seismograph Service Corporation
TULSA, OKLAHOMA, U. S. A.

# BULLETIN

*of the*

## AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, CHESTNUT-SMITH BUILDING, TULSA, OKLAHOMA



C. L. MOODY, *Editor*
THE OHIO OIL COMPANY, SHREVEPORT 91, LOUISIANA

ASSOCIATE EDITORS

| | |
|---|---|
| GENERAL | K. C. HEALD, Gulf Oil Corporation, Box 1166, Pittsburgh 30, Pa. |
| | HUGH D. MISER, U. S. Geological Survey, Washington 25, D. C. |
| | L. L. NETTLETON, Gravity Meter Exploration Company, 1348 Esperson Bldg., Houston, Tex. |
| | THERON WASSON, Pure Oil Company, 35 E. Wacker Drive, Chicago 1, Ill. |
| APPALACHIANS | RICHARD E. SHERRILL, University of Pittsburgh, Pittsburgh 13, Pa. |
| NORTH-CENTRAL STATES | R. B. NEWCOMBE, Superior Oil Company, Grand Rapids, Mich. |
| KANSAS | EDWARD A. KOESTER, 302 Orpheum Building, Wichita 2, Kan. |
| OKLAHOMA | |
| *Western* | ROBERT H. DOTT, Oklahoma Geological Survey, Norman, Okla. |
| *Eastern* | JOHN L. FERGUSON, Amerada Petroleum Corp., Box 2040, Tulsa 1, Okla. |
| TEXAS | |
| *North and Central* | J. B. LOVEJOY, Gulf Oil Corporation, Fort Worth 1, Tex. |
| *Northeastern* | C. I. ALEXANDER, Magnolia Petroleum Company, Tyler, Tex. |
| *San Antonio* | JOHN R. SANDIDGE, Magnolia Petroleum Company, San Antonio 5, Tex. |
| *Permian Basin* | E. RUSSELL LLOYD, Box 1026, Midland, Tex. |
| GULF COAST | SIDNEY A. JUDSON, Texas Gulf Producing Company, Houston 1, Tex. |
| | MARCUS A. HANNA, Gulf Oil Corporation, Houston 1, Tex. |
| EASTERN GULF | HENRY N. TOLER, Southern Natural Gas Company, Jackson, Miss. |
| ARKANSAS AND NORTH LOUISIANA | ROY T. HAZZARD, Gulf Refining Company of Louisiana, Shreveport 93, La. |
| ROCKY MOUNTAINS | A. E. BRAINERD, Continental Oil Company, Denver 2, Colo. |
| CALIFORNIA | W. D. KLEINPELL, Box 1131, Bakersfield, Calif. |
| | E. R. ATWILL, Union Oil Company of California, 617 W. 7th, Los Angeles 14 |
| CANADA | THEODORE A. LINK, Imperial Oil Limited, Toronto, Ontario |
| SOUTH AMERICA | HOLLIS D. HEDBERG, Gulf Oil Corporation, 17 Battery Pl., New York 4, N.Y. |



THE BULLETIN is published by the Association on the 15th of each month.

EDITORIAL AND PUBLICATION OFFICE AND ASSOCIATION HEADQUARTERS, Chestnut-Smith Building, 624 South Cheyenne Avenue, Tulsa, Oklahoma. Post Office, Box 979, Tulsa 1. Cable address: AAPEGOL.

BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is $15 per year (separate numbers, $1.50), prepaid to addresses in the United States; outside the United States, $15.40.

CLAIMS FOR NON-RECEIPT must be sent within 3 months of date of publication, to be filled gratis.

BACK NUMBERS, if available, may be ordered from Headquarters. Price list on request.

| | *Mem.* | *Non-Mem.* |
|---|---|---|
| Cloth-bound Bulletin, Vols. 12 (1928)-15 (1931) incl., each | $5.00 | $6.00 |

| SPECIAL PUBLICATIONS | *Mem.* | *Non-Mem.* | SPECIAL PUBLICATIONS | *Mem.* | *Non-Mem.* |
|---|---|---|---|---|---|
| 1936. Geology of Tampico Region | 3.50 | 4.50 | 1946. Directory of Geological Material in North America.. | .75 | .75 |
| 1936. Map of Southern California | .50 | .50 | 1947. Comprehensive Index '17-'45 | 3.00 | 4.00 |
| 1938. Miocene Strat. California | 4.50 | 5.00 | 1948. Typical Amer. Oil Fields, III | 3.50 | 4.50 |
| 1941. Future Oil Provinces | 1.00 | 1.50 | | | |
| 1944. Tectonic Map of U. S. | 2.00 | 2.00 | | | |

**Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to**

## THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

J. P. D. HULL, BUSINESS MANAGER
ELMER W. ELLSWORTH, ASSISTANT BUSINESS MANAGER
BOX 979, TULSA 1, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

# THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.

## OFFICERS FOR THE YEAR ENDING MARCH, 1949

PAUL WEAVER, *President*, Houston, Texas
ROY M. BARNES, *Vice-President*, Los Angeles, California
J. V. HOWELL, *Secretary-Treasurer*, Tulsa, Oklahoma
C. L. MOODY, *Editor*, Shreveport, Louisiana

The foregoing officers and the *Past-President*, C. E. DOBBIN, Denver, Colorado, constitute the Executive Committee

## DISTRICT REPRESENTATIVES (Terms expire after annual meetings of years shown in parentheses)

*Amarillo:* Wendell G. Sanford (50), Pampa, Tex.
*Appalachian:* Fenton H. Finn (49), Pittsburgh, Pa.
*Canada:* C. S. Corbett (49), Calgary, Alberta
*Capital:* W. G. Pierce (50), Washington, D.C.
*Corpus Christi:* O. G. McClain (49), Corpus Christi, Tex.
*Dallas:* Joseph M. Wilson (49), John W. Clark (50), Dallas, Tex.
*East Oklahoma:* E. Floyd Miller (49), Sam H. Woods (49), Ralph A. Brant (50), Tulsa; Homer H. Charles (50), Bartlesville
*Fort Worth:* Lynn K. Lee (49), Fort Worth, Tex.
*Great Lakes:* E. E. Rehn (49), Evansville, Ind.; J. A. Brown (50), Evansville, Ind.
*Houston:* Harold L. Geis (49), Charles L. Lake (49), Harry C. Spoor, Jr. (49), J. Archer Culbertson (50), Robert B. Mitchell (50), A. L. Selig (50), Houston, Tex.
*Michigan:* Charles K. Clark (49), Saginaw, Mich.
*New Mexico:* Reuel L. Boss (49), Hobbs, N.Mex.
*New York:* Hollis D. Hedberg (49), Walter K. Link (50), New York City
*Pacific Coast:* Gordon R. Bell (49), Los Angeles; W. S. W. Kew (49), San Francisco; Lowell W. Saunders (49), Bakersfield; Frank B. Carter (50), Los Angeles; Thomas J. Fitzgerald (50), Bakersfield; Allison J. Salari (50), San Francisco, Calif.
*Rocky Mountains:* A. F. Barrett (49), E. J. Boos (50), Casper, Wyo.; Kirk C. Forcade (50), Denver, Colo.
*Shreveport:* B. W. Blanpied (49), Shreveport, La.
*South America:* J. M. Patterson (49), Caracas, Venezuela; Walter M. Chappell (50), Bogota, Colombia
*Southeast Gulf:* Henry N. Toler (49), Jackson, Miss.
*Southern Louisiana:* J. W. Hoover (49), New Orleans, La.
*So. Permian Basin:* F. H. McGuigan (49), Max David (50), Midland, Tex.; Vincent C. Perini (50), Abilene, Tex.
*South Texas:* George H. Coates (49), Robert Scott Mann (50), San Antonio
*Tyler:* C. I. Alexander (49), Tyler, Tex.
*West Oklahoma:* J. T. Richards (49), Oklahoma City; Jerome M. Westheimer (50), Ardmore
*Wichita:* Frederick G. Holl (49), Wichita, Kan.
*Wichita Falls:* H. L. Rickard (50), Wichita Falls, Tex.

## DIVISION REPRESENTATIVES

*Paleontology and Mineralogy:* R. Dana Russell (49), San Diego, Calif.; Henryk B. Stenzel (49), Austin, Texas

## PACIFIC SECTION (Chartered, March, 1925)

WILLIAM P. WINHAM, *President*, Standard Oil Company, Box 2437, Terminal Annex, Los Angeles 54, California
HARVEY W. LEE, *Vice-President*, Union Oil Company, 617 W. 7th St., Los Angeles 14, California
P. H. GARDETT, *Secretary-Treasurer*, General Petroleum Corp., 108 W. 2d St., Los Angeles 12, California
Membership restricted to members of the Association in good standing, residing in Pacific Coast states. Dues: $2.00 per year.

## SOUTH TEXAS SECTION (Chartered, April, 1929)

MARION J. MOORE, *President*, Sunray Oil Corporation, 1610 Milam Building, San Antonio, Texas
MAURICE E. FORNEY, *Secretary-Treasurer*, Atlantic Refining Company, 1728 Milam Building, San Antonio, Texas
Membership limited to persons eligible to Association membership. Dues: $2.50. Annual meeting in October.

## EASTERN SECTION (Chartered, April, 1946)

W. P. HAYNES, *President*, Standard Oil Company (N.J.), Room 2150, 30 Rockefeller Plaza, New York, N.Y.
DOUGLAS A. GREIG, *Secretary*, Standard Oil Company (N.J.), Room 2150, 30 Rockefeller Plaza, New York, N.Y.
Membership restricted to members of the Association in good standing, residing in New York district.

## DIVISION OF PALEONTOLOGY AND MINERALOGY
### SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Organized, March, 1927; affiliated, March, 1928; chartered, technical division, April, 1930)
R. DANA RUSSELL, *President*, U. S. Navy Electronics Lab., San Diego, California
HENRYK B. STENZEL, *Secretary-Treasurer*, Bureau of Economic Geology, Austin 12, Texas

SEND DUES, SUBSCRIPTIONS AND ORDERS FOR BACK NUMBERS TO BOX 979, TULSA 1, OKLAHOMA
The Society and the Paleontological Society jointly issue six times a year the *Journal of Paleontology*, J. Marvin Weller, University of Chicago, Chicago 37, Illinois, and A. S. Warthin, Vassar College, Poughkeepsie, New York, editors: subscription, $6.00. The *Journal of Sedimentary Petrology*, W. H. Twenhofel, editor, University of Wisconsin, Madison, Wisconsin, is issued three times a year: subscription, $3.00. Single copies, *Journal of Paleontology*, $2.00; *Journal of Sedimentary Petrology*, $1.50. Society dues: with *Jour. Pal.*, $5.00; with *Jour. Sed. Petrology*, $3.00; with both, $8.00 per year.

## AFFILIATED SOCIETIES (Dates of affiliation in parentheses)

**Abilene Geological Society**, Abilene, Texas (47). Riley G. Maxwell, Secy., Box 1939
**Alberta Society of Petroleum Geologists**, Calgary, Alberta (31). J. G. Gray, Secy., California Std. Co., 700 Lancaster Bldg.
**Appalachian Geological Society**, Charleston, W.Va. (31). Alan H. McClain, Secy., Owens, Libby-Owens Gas Dept., Box 4158
**Ardmore Geological Society**, Ardmore, Oklahoma (36). Frank Millard, Secy., Schlumberger Well Surveying Corp., Box 747
**Associacao Brasileria de Petroleo**, Salvador, Bahia, Brazil (47).
**Corpus Christi Geological Society**, Corpus Christi, Texas (43). H. C. Cooke, c/o O. G. McClain, 224 Wilson Building
**Dallas Geological Society**, Dallas, Texas (35). H. V. Tygrett, Secy., Atlantic Refining Company, Box 2819
**East Texas Geological Society**, Tyler, Texas (32). G. C. Clark, Secy., Stanolind Oil and Gas Company, Box 660
**Fort Worth Geological Society**, Fort Worth, Texas (31). Millicent A. Renfro, Secy., Texas Pacific Coal and Oil Co., Box 2110
**Houston Geological Society**, Houston, Texas (32). R. R. Rieke, Secy., Schlumberger Well Surveying Corporation
**Illinois Geological Society** (39). Halbert H. Bybee, Secy., Carter Oil Company, Box 568, Mattoon
**Indiana-Kentucky Geological Society** (38). E. J. Combs, Secy., Sun Oil Company, Box 717, Evansville, Ind.
**Kansas Geological Society**, Wichita, Kansas (31). Shirley E. Lenderman, Secy., Stanolind Oil and Gas Company
**Michigan Geological Society** (37). H. J. Hardenberg, Secy., Michigan Geological Survey, Lansing
**Mississippi Geological Society**, Jackson, Miss. (41). E. T. Monsour, Secy., Consultant, Box 2571, West Jackson
**New Orleans Geological Society**, New Orleans, La. (43). Ame Vennema, Secy., Schlumberger Well Surveying Corporation
**North Texas Geological Society**, Wichita Falls, Texas (38). Joseph W. McDonald, Secy., Shell Oil Company, Inc., Box 2010
**Oklahoma City Geological Society**, Oklahoma City, Okla. (31). John Janovy, Secy., Tide Water Associated Oil Company, 918 Hales Building
**Panhandle Geological Society**, Amarillo, Texas (32). Fred S. Alexander, Secy., Standard Oil Company of Texas, Box 2087
**Shawnee Geological Society**, Shawnee, Oklahoma (31). Marcelle Mousley, Secy., Atlantic Refining Company, Box 169
**Shreveport Geological Society**, Shreveport, Louisiana (32). R. T. Wade, Secy., Schlumberger Well Surveying Corporation, Box 92
**Society of Exploration Geophysicists** (32). E. V. McCollum, Secy., 515 Thompson Building, Tulsa, Okla.
**South Louisiana Geological Society**, Lake Charles, La. (37). H. L. Tipsword, Secy., Magnolia Petroleum Company, Box 872
**Tulsa Geological Society**, Tulsa, Oklahoma (31). Noel Evans, Secy., Consultant, 1510 Philtower Building
**Southeastern Geological Society**, Tallahassee, Fla. (44). Eleanor T. Caldwell, Secy., Humble Oil and Refining Co., Box 506
**West Texas Geological Society**, Midland, Texas (38). Clyde W. Turner, Secy., Gulf Oil Corp., Box 1150
**Wyoming Geological Associaton**, Box 545, Casper (45). H. E. Summerford, Secy., Chemical Laboratories, Inc., Box 279
**Yellowstone-Bighorn Research Association, Inc.** (44). W. T. Thom, Jr., Secy., Princeton, N.J.

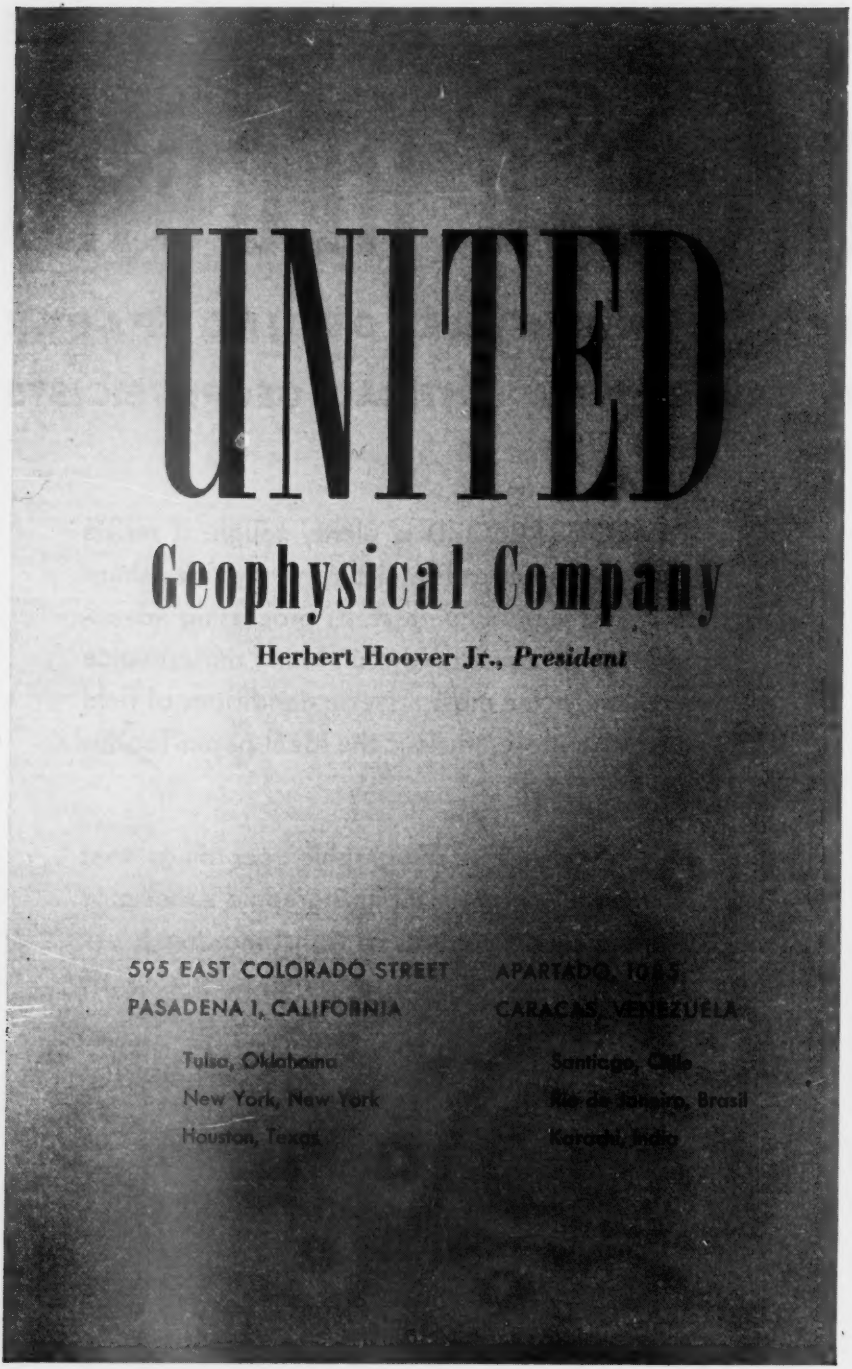
# HALOID RECORD

## SEISMOGRAPH RECORDING PAPER IS FAVORED BY CRITICAL GEOPHYSICISTS

HALOID RECORD is plenty tough. It resists heat and withstands moisture. It provides sharp lines and legible contrast. Its processing advantage and consistently uniform performance even under the most adverse conditions of field and laboratory, make it the ideal paper for this work.

For superior seismographic recordings that successfully combine photographic excellence with an amazing ability to withstand abuse, use Haloid Record—the paper that's favored by critical geophysicists.

**THE HALOID COMPANY**
**48-7 Haloid St., Rochester 3, N.Y.**


UNITED
Geophysical Company
Herbert Hoover Jr., President
595 EAST COLORADO STREET
PASADENA 1, CALIFORNIA
APARTADO, 1083
CARACAS, VENEZUELA
Tulsa, Oklahoma
New York, New York
Houston, Texas
Santiago, Chile
Rio de Janeiro, Brasil
Karachi, India

Sure, oil exploration costs can be high . . . but you don't need such a drastic solution! A Mayes-Bevan Gravity Meter Survey gives you a reliable preliminary investigation that is ECONOMICAL! High priced, detailed exploration techniques are out of the question over a large potential producing province. Mayes-Bevan has the answer. Let them localize your areas, indicating in just which LIMITED sectors further, more elaborate, explorations should be profitable. So lay that pistol down . . . and send for Mayes-Bevan!

MAYES-BEVAN GRAVITY METER SURVEYS COMPANY

KENNEDY BLDG. TULSA, OKLAHOMA

An A.A.P.G. Publication!

# TECTONIC MAP

Of The

# UNITED STATES

Prepared under the Direction of the Committee on Tectonics, Division of Geology and Geography, National Research Council.

CHESTER R. LONGWELL, Chairman, PHILIP B. KING, Vice-Chairman
CHARLES H. BEHRE, WALTER H. BUCHER, EUGENE CALLAGHAN, D. F. HEWETT, G. MARSHALL KAY, ELEANORA B. KNOPF, A. I. LEVORSEN, T. S. LOVERING, GEORGE R. MANSFIELD, WATSON H. MONROE, J. T. PARDEE, RALPH D. REED, GEORGE W. STOSE, W. T. THOM, JR., A. C. WATERS, ELDRED D. WILSON, A. O. WOODFORD

---

## A Geologic Map of the United States and Adjacent Parts of Canada and Mexico

Geologic structure, as evidenced and interpreted by a combination of outcropping areas, bedrock, surface disturbance, and subsurface deformation, is indicated by colors, symbols, contours, and descriptive explanation. Igneous, metamorphic, and selected areas of sedimentary rock are mapped. Salt domes, crypto-volcanic disturbances, and submarine contours are shown.

The base map shows state boundaries, rivers, a pattern of cities, and 1-degree lines of latitude and longitude.

The scale is 1:2,500,000, or 1 inch = 40 miles. Printed in 7 colors, on 2 sheets, each about 40 x 50 inches. Full map size is about 80 x 50 inches.

---

**PRICE, POSTPAID**

**$2.00 rolled in mailing tube**

**$1.75 folded in manila envelope**

**$1.50 in lots of 25, or more, rolled or folded**

---

**The American Association of Petroleum Geologists**
**Box 979, Tulsa 1, Oklahoma, U.S.A.**

## AT OUR MIDLAND PLANT . . .

# Failing -TRAINED MECHANICS

### to repair, service, or overhaul your drilling equipment

**In Stock AT ALL TIMES**

- BEARINGS
- KELLYS
- KELLY BUSHINGS
- WATER SWIVELS
- DRILL PIPE
- DRILLING BITS
- SUBSTITUTES
- PUMP LINERS
- PUMP PISTONS
- PISTON RODS
- PUMP VALVES
- WIRE LINE
- HOSE

FAILING'S PLANT FACILITIES at MIDLAND, Texas have recently been expanded to include a modern repair and overhauling department.

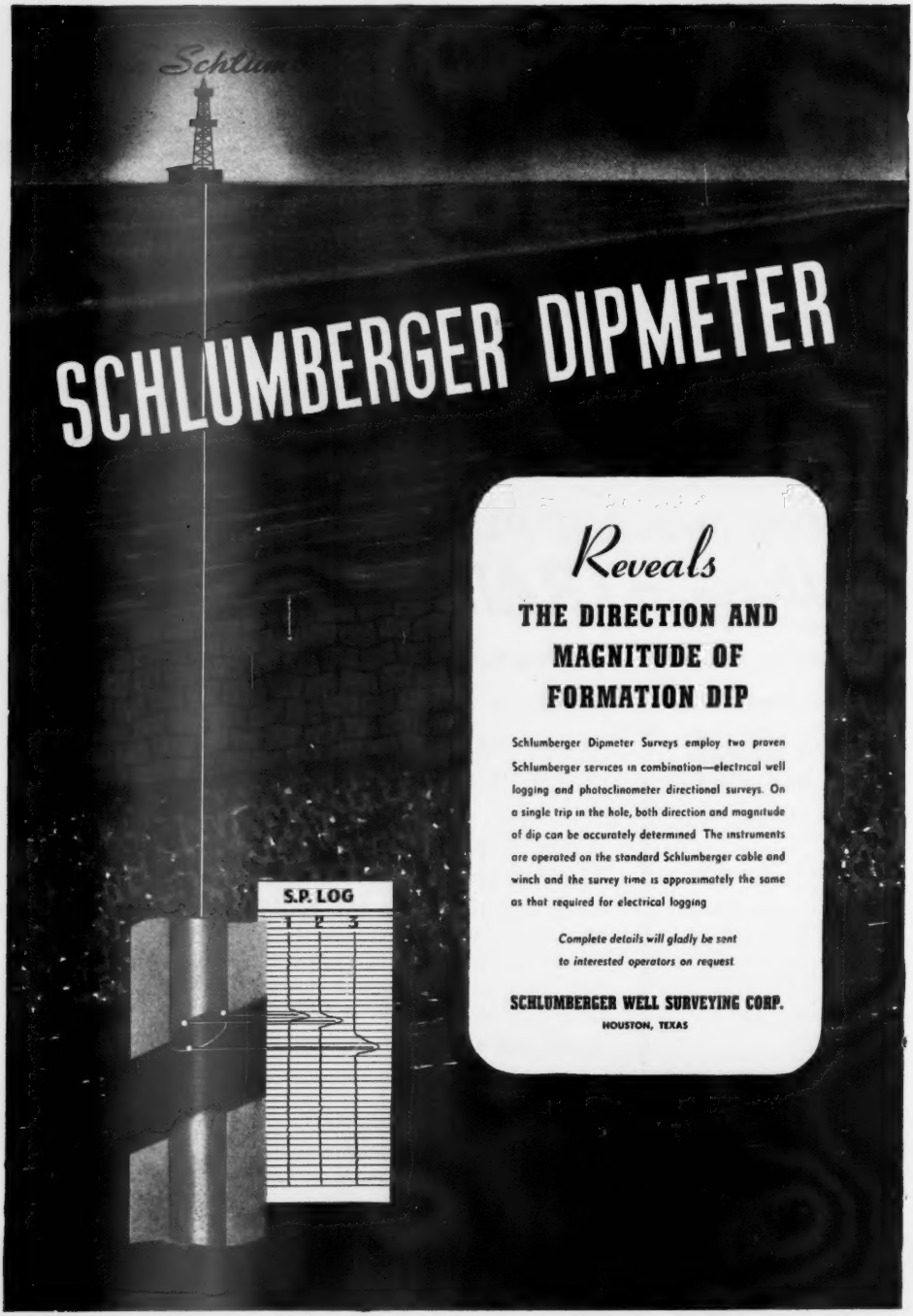
If you are operating in the Midland area, take your rig to the FAILING plant where it will receive expert attention from mechanics trained in the FAILING factory. These men know just what it takes to make a drill click. Genuine FAILING parts are available from our large stock at Midland. Day and night service.

Appointments are not necessary, but it would be helpful if you could schedule your job in advance. Write, wire or telephone Jimmy Helton, manager . . . Telephone: 1245. P.O. Box: 1566. Address: 2200 West Wall St., Midland, Texas.

**Geo. E. Failing Supply Co.**

"HOME OF THE HOLEMASTERS"

ENID, OKLAHOMA, U.S.A.


SCHLUMBERGER DIPMETER
S.P. LOG
1 2 3
Reveals
THE DIRECTION AND MAGNITUDE OF FORMATION DIP
Schlumberger Dipmeter Surveys employ two proven Schlumberger services in combination—electrical well logging and photoclinometer directional surveys. On a single trip in the hole, both direction and magnitude of dip can be accurately determined The instruments are operated on the standard Schlumberger cable and winch and the survey time is approximately the same as that required for electrical logging
Complete details will gladly be sent to interested operators on request
SCHLUMBERGER WELL SURVEYING CORP.
HOUSTON, TEXAS

# *Bulletin* Advertisers


Aero Service Corporation ..... li
American Optical Company .....
American Paulin System ..... xli
American Petroleum Institute ..... xlviii

Baker Oil Tools, Inc. ..... xliv
Baroid Sales Division ..... xxix
Barret, William M., Inc. .....
Bausch and Lomb Optical Company ..... xliii

Century Geophysical Corporation .....
..... between xxxii and xxxiii

Dowell Incorporated ..... lv

Eastman Oil Well Survey Company .....
Economic Geology Publishing Company ..... xxxvi

Failing, Geo. E., Supply Company ..... v
Fairchild Aerial Surveys, Inc. ..... xxxiii
Frost Geophysical Corporation ..... xxvi

General Geophysical Company ..... xxxii
Geolograph Company, Inc. ..... xxxix
Geophoto Services ..... xlvi
Geophysical Service, Inc. ..... Cover iii
Geotechnical Corporation ..... xxxvi
Gravity Meter Exploration Company ..... xxxi

Halliburton Oil Well Cementing Co. .....
Haloid Company ..... iii
Hawthorne, Herb J., Inc. ..... xl
Heiland Research Corporation ..... xlv
Hughes Tool Company ..... Cover iv
Hutchinson Bag Company .....

Independent Exploration Company .....

Journal of Geology .....
Journal of Paleontology .....
Journal of Sedimentary Petrology .....

Keystone Exploration Company .....
Koenig Iron Works .....

Lane-Wells Company ..... xxxiv

Marine Exploration Company ..... xxxv
Mayes-Bevan Company ..... facing iv
McCollum Exploration Company ..... viii

National Geophysical Company ..... lvi
North American Geophysical Company ... xxx

Oil Base, Inc. .....

Petty Geophysical Engineering Company xxviii
Port City Cabinet Works ..... l

Reed Roller Bit Company ..... xlvii
Reliable Geophysical Company ..... xxvi
Repubic Exploration Company .....
Robert H. Ray Company ..... xxiv
Rogers-Ray, Inc. ..... xxv

Schlumberger Well Surveying Corp. ..... vi
Security Engineering Company, Inc. ..... xlix
Seismic Engineering Company .....
Seismic Explorations, Inc. ..... xxvii
Seismograph Service Corporation ..... Cover ii
Society of Exploration Geophysicists .....
Southern Geophysical Company .....
Sperry-Sun Well Surveying Company .....
States Exploration Company ..... xxxviii
Sullivan Division, Joy Mfg. Co. .... xxii-xxiii

Thompson Tool Company ..... xlii
Triangle Blue Print and Supply Company xxxvi

United Geophysical Company ..... iv
Universal Exploration Company ..... xxxvi

Wallace and Tiernan Products, Inc. .... xxxvii
Western Geophysical Company ..... liv


## PROFESSIONAL CARDS

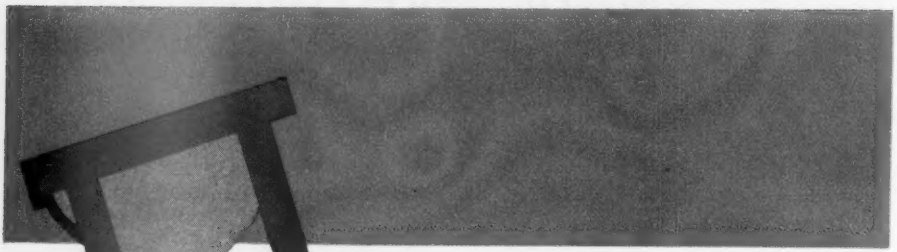

California ..... ix
Colorado ..... ix
Illinois ..... x
Indiana ..... x
Kansas ..... x
Louisiana ..... x
Mexico ..... x
Mississippi ..... x-xi
Montana ..... xi
New Mexico ..... xi
New York ..... xi
North Carolina ..... xi
Ohio ..... xi
Oklahoma ..... xi-xii
Pennsylvania ..... xii
Texas .... xii, xiii, xiv, xv, xvi
West Virginia ..... xvii
Wyoming ..... xvii


## GEOLOGICAL AND GEOPHYSICAL SOCIETIES


Abilene ..... xx
Appalachian ..... xxi
Ardmore ..... xix
Corpus Christi ..... xx
Dallas ..... xx
East Texas ..... xx
Exploration Geophysicists xviii
Fort Worth ..... xx
Houston ..... xx
Illinois ..... xviii
Indiana-Kentucky ..... xviii
Kansas ..... xviii
Michigan ..... xix
Mississippi ..... xix
New Orleans ..... xviii
North Texas ..... xxi
Oklahoma City ..... xix
Pacific Section ..... xviii
Panhandle ..... xxi
Pittsburgh ..... xx
Rocky Mountain ..... xviii
Shawnee ..... xix
Shreveport ..... xix
Southeastern ..... xviii
South Texas Section ..... xxi
South Louisiana ..... xix
Tulsa ..... xix
West Texas ..... xxi
Wyoming ..... xxi


# Articles for August *Bulletin*


**Summary of Middle Ordovician Bordering Allegheny Synclinorium** — By Marshall Kay
**Cambrian and Ordovician Rocks in Michigan and Adjacent Areas** — By George V. Cohee
**New York Subsurface Geology** — By E. T. Heck
**Subsurface Trenton and Sub-Trenton Rocks in Ohio, Pennsylvania, and West Virginia** — By Charles R. Fettke
**Trenton and Sub-Trenton Outcrop Areas in New York, Pennsylvania, and Maryland** — By Frank M. Swartz
**Trenton and Sub-Trenton Stratigraphy of Northwest Belts of Virginia and Tennessee** — By C. E. Prouty
**Trenton and Pre-Trenton of Kentucky** — By A. C. McFarlan and W. H. White
**Kentucky Subsurface** — By Coleman D. Hunter



EXPERIENCE COUNTS

This is especially true in seismic exploration. Years of experience in the seismic field are necessary to produce accurate interpretation of results.

Being a leader in this field since 1923, McCollum Exploration is eminently qualified to furnish accurate, dependable information that can be accepted with confidence. Get the benefit of this experience by using McCollum Exploration experts for land or marine seismic exploration.

McCOLLUM SINCE 1923
Exploration Company

853 ESPERSON BUILDING • HOUSTON 2, TEXAS

Pioneers in
REFRACTION SHOOTING
WELL SHOOTING
REFLECTION SHOOTING
MARINE SHOOTING

Volume 32 Number 7

BULLETIN
*of the*
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JULY, 1948

# SOCIAL TRENDS IN SCIENCE[1]

CARROLL E. DOBBIN[2]
Denver, Colorado

## INTRODUCTION

In general, there have been three stages in man's relation to society: first, that in which certain men had the right to exploit other men—slavery, serfdom, and the like; second, the right of each man to receive rewards from society proportional to his contributions thereto; and third, the present stage of spreading foreign "isms" that teach and practice, more or less, the dialectic materialism of Karl Marx (1818–1883) and Friedrich Engels (1820–1895)—a stage featured by increasing tensions, doubts, and revaluations, by efforts to create unity by imposing uniformity instead of tolerating variety, by marked shifts from the relative complacency and serene security of thirty-five years ago, by proofs that excessive debt invites dictators and doom; but which, under the applications of an accelerated, cooperating, democratic, objective, optimistic, skeptical, and unacquisitive science, can evolve relatively soon into the most enjoyable society yet known. Platitudinous moralizings? Not if man, having completed most of his biological evolution, will begin to evolve morally.

## SCIENCE AND SOCIETY

The golden ages of democracy have always been the brilliant ages of genius, when man was relatively free and his confidence and creative instinct were unrestrained. The Greece of Pericles, in 431 B. C., was the apex of a golden age of

[1] Presidential address, 33d annual meeting, Denver, April 27, 1948.

[2] United States Geological Survey.

artistic, intellectual, and material achievement and speculative science that flourished in a democratic civilization scarcely attained since—a society of intellect and liberty in the West that had conquered materialism and despotism in the East.

Rome, the conqueror, conquered in turn by Greek culture, suffered the social and economic schemes of Julius Caesar (100–44 B. C.) and his successors, who, like some others since, seemingly ignored the results of the similar drastic measures of Lycurgus (9th century ? B. C.), Solon (639?–559 B. C.), Tiberius Gracchus (162?–133 B. C.), and others; democracy degenerated into tyranny—as Aristotle (384–322 B. C.) predicted it would; all civil liberties were destroyed in totalitarianism; and the western world plunged for 1,000 years into the intellectual stagnation of medievalism.

Rejuvenated in the Renaissance, democracy contributed in the 16th and 17th centuries the beginnings of an age of experimental science that marched gradually through and over entrenched ignorance, misconception, prejudice, and the fallacies of ancient myth and error to the present spectacular scientific and industrial age.

The announcement by Copernicus (1473–1543) that the earth revolves around the sun and that man is not at the center of the universe produced the greatest consternation in certain quarters, and marked a new epoch in human thought. The philosophies of Descartes (1596–1650) and Newton (1642–1727) and the theories of Darwin (1809–1882) and Einstein (1879– ) stimulated equally great revolutions in human understanding, and now comes the new science with its promise of incredible advances. In other words, science has often turned the pages of human history but in turning the present page it must challenge vigorously those forces that seek false liberty and security at any cost and especially by the misuse of the contributions of science.

That minor revolutions are occurring in science, with positive results on society, is attested by the close dependency of one science upon another, such as the explanation of chemical substance and chemical reactions in terms of the new physics, innovations of genetics in biology, actions of enzymes, advances in immunology, studies of proteins and viruses in biochemistry, psychosomatic medicine, *etc.* Physics, a static science in the early nineties, because, seemingly all the fundamental principles had been discovered, has been rejuvenated to a feverish pitch by the subsequent discovery of X-rays, the electron, and radium and by the development of relativity, quantum mechanics, and nuclear physics with its radioactive isotopes. Elements have been transformed into other elements, and space, time, and gravitation have assumed new and wonderful meanings.

## ADMINISTRATION

Superior scientific administrators will analyze and act constructively upon their many new opportunities and responsibilities, in order to control the impact of accelerated science upon society and to improve and maintain our secular cul-

ture, for science alone can not handle the new forces; in fact, the success of these administrators and their organizations will depend to a large extent on their knowledge of most phases of human nature. They will investigate the proper role of government in subsidizing science; they will plan for a greater and more prosperous science, even though some scientists adhere to the bedrid argument that planning violates the dignity of science; they will know at least the fundamentals of business management, in order to apply their technical equipment effectively; they will assist in overcoming human gullibility and general ignorance; they will know that they are not omnicompetent and will work closely with culture and religion in improving spiritual and temporal relations, emphasizing the basic virtue of science, namely, scrupulous honesty; they will know that sovereignty in science, that is, internal regulation and external independence, with the hand of cooperation extended to all, can, when aggressively and positively maintained, be of supreme service; they will reflect upon the surprise of Anacharsis, who, on seeing the people assembled at Athens in 590 B. C., expressed surprise and stated that in Greece wise men pleaded causes and fools determined them; they will heed Plato's (427?–347 B. C.) warning to Dion to guard against the austerity that is the companion of solitude and melancholy; and they will administer gradually and circumspectly, else they may suffer the ostracism in some form—the injuries and capricious treatment that all men once distinguished by birth, reputation, eloquence, or superior parts, were liable to suffer, so that the fury of envy, who delights in the disgrace of superior characters and loses a part of her rancour by their fall, might be pacified.

### POLITICS

Demosthenes (384?–322 B. C.) stated that if two roads had been shown him at first, the one leading to the rostrum and the business of the assembly, and the other to certain destruction, and he could have foreseen the evils that awaited him in the political walk, the fears, the envy, the calumny, and contention, he would have chosen that road which led to immediate death. Thus did that great impassioned reasoner rate politics, the science and art of government.

Past events prove, however, that science must be more familiar with politics in order to determine the kind of treatment it will receive in an increasingly complicated social set-up featured by closer interdependence. In other words, science is performing mightily but is floundering somewhat in the midst of potential plenty at a time when the bulkhead between science and politics is weakening. As has been proposed often, scientists should inform the public of their worth and works and be more active in public affairs, so that a stabilizing influence against pressure groups will be provided and science will be no longer the party of the second part.

As Ralph Waldo Emerson (1803–1882) wrote, politics rests on necessary foundations and can not be treated with levity; in fact, according to the American Association for the Advancement of Science, science has been in politics since March

3, 1863, when politicians created the National Academy of Sciences to advise the Government on scientific functions and to confound the men of Europe.[3]

## ENGLISH

In an age when nations are propagandizing by wholesale, scientists and engineers, who make a fetish of precision in special knowledge, often derail their thoughts by a deplorable bungling of words, and especially so now when persuasion is almost a lost art. Facility in language and felicity of expression culled from the luckiest moods of users of good (not perfect) English assist in ventilating awkward subjects, in analyzing the distortions of enthusiasm, claptrap, and flapdoodle, in stimulating vigorous thinking, arguments, and style, in perscribing and particularizing nicely, in lessening higgling and other fusses in futility, and in invigorating those floundering in bogs of Nestorian caution, delusive exactness, dull and decadent conformity, and similar morasses of bewildering unimportance.

The satisfaction gained by speaking and writing good English more than requites the effort spent in learning it. "Clarity is not infantile, nor is complex opacity profound;" and Mark Twain once said that the difference between the right word and the almost right word is like the difference between lightning and a lightning bug.

Aristotle used to say to a new student: "Speak, young man, so that I may see you." In other words, speech reveals personality, that mysterious, elusive, undefinable thing responsible for about 85 per cent of success; and honest eloquence lends charm to truth and makes justice invincible when fully supported, even though some great men have had to learn by sad experience that their well chosen words could not straighten out the affairs of the world.

## GEOLOGISTS AND SOCIETY

As chairman of the Committee on Applications of Geology of this Association, I urged at the annual meeting of the American Institute of Mining and Metallurgical Engineers in New York City, February 17, 1941, that the worth and works of geologists and geophysicists be advertised vigorously to appreciative and influential laymen.[4] It has been very gratifying since, therefore, to see the increased interest in and recognition of these practitioners of earth science under the stimulus of aggressive leadership within and closer relations with each other and with other scientists and engineers; indeed, it is a supreme satisfaction to see the seriousness and maturity of mind evinced, as never before, by most prominent men.

Geologists, unlike other physical scientists, have no long, outstanding record as developers of new, dynamic, and fruitful scientific concepts. They are, however, reviewing their dogmas critically; they are refusing to scatter their force by sub-

[3] H. A. M., "Science in Politics," *Bull. Amer. Assoc. Adv. Sci.*, Vol. 5, No. 7 (1946).

[4] *Amer. Inst. Min. Met. Eng. Tech. Pub. 1382* (1941), pp. 1–2.

scribing to the blindman's buff game of conformity, consistency, and custom, even though, like most great scientists of old, they may be misunderstood; they are casting off their peculiar ivory tower; they are conscious of their greater responsibilities in guiding geological education; they are endeavoring to revitalize and unite geology by creating a single, strong, and aggressive geological agency, namely, the American Geological Institute; they are beginning to enlighten the hungry public and to formulate social policies; they are advising instruction beyond basic training, such as courses in cultural and social sciences; and they are examining all major trends much more critically than heretofore.

As Emerson wrote,[5]

> There is a time in every man's education when he arrives at the conviction that envy is ignorance; that imitation is suicide; that he must take himself for better or worse as his portion; that though the wide universe is full of good, no kernel of nourishing corn can come to him but through his toil bestowed on that plot of ground which is given him to till. The power which resides in him is new in nature, and none but he knows what that is which he can do, nor does he know until he has tried.

In tilling their plot of ground—the history of the earth and its life as recorded in rocks—geologists utilize the tools of all natural sciences in the grandest and sublimest of all settings—the outdoors. It is, therefore, averred that they are especially and peculiarly endowed by training, experience, and vision to supplement their fundamental scientific researches by leading aggressively, impartially, and soundly in the cultivation of that social field, the crop from which will be an advanced and stable society featured by the power and prestige of scientists and engineers.

[5] Ralph Waldo Emerson, "Self-Reliance."

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32. NO. 7 (JULY, 1948), PP. 1216-1220.

# INTEGRATION IN EXPLORATION[1]

CECIL H. GREEN[2]
Dallas, Texas

It is a particular privilege to address not only geologists, paleontologists, and geophysicists of the petroleum industry, but also a group of specialists in mining exploration. To you who are mining geophysicists, I hope that I am correct in assuming that the philosophy of my discussion does have a considerable bearing also on the search for new ore deposits, even though colored by constant reference to petroleum.

No doubt, exploration has attained a new high level of importance in the mining field, as it has for petroleum, where the current rate of domestic oil production has reached an all-time maximum—even exceeding widely the greatest rate established during World War II.

The ratio of annual production versus proved reserves is an important indicator of condition. In the domestic oil industry we have been able to do no better than to maintain a near-constant value for this index over the 11-year period from 1937 through 1947, even though the total expenditure for exploration—leases, geological and geophysical work plus wildcat drilling—has increased more than four times during the same period.[3]

Looking to the future—it is at least conjectural, whether or not we shall be able to maintain the same ratio of annual production versus proved oil reserves for a similar new period by the sole process of increasing 1937 expenditures another four times. Actually, such an accomplishment is probably dependent on the strategy of following several other avenues, as well as this one of increased effort, for example,

a. To discover an extensive new province, such as the continental shelf, which we are now entering,

b. To effect distinct improvements in the performance of present geophysical apparatus,

c. To improve the integration of existing exploration methods.

You will note that I have not included the possible invention of an entirely new exploration method—the explanation being that in studying the magnetic, gravitational, electrical, chemical, radioactive, and acoustical properties, we are apparently utilizing already practically every physical property of the earth.

Therefore, in the absence of immediate prospects at least, for a panacea, it appears more necessary than ever to direct our thinking toward sharpening present exploration tools and to better coordination of their use. In other words,

[1] Presidential address, presented at the annual meeting of the Society of Exploration Geophysicists, Denver, Colorado, on Tuesday, April 27, 1948.

[2] Geophysical Service Inc.

[3] H. J. Struth, "1947 Oil Discoveries Largest since 1937," *Petrol. Eng.* (January, 1948).

the effectiveness of future exploration programs would seem to depend more than ever upon how well we can combine good instruments and capable people.

Of these two elements, capable people is the more important, as indicated by the diversity of talents required in the following exploration pattern.

First, if our field efforts in a particular region are to count for much, we must have direction. This means that logical inspiration must first be provided by a digest of geological background information in combination with all available and pertinent geophysical data. It follows that the accuracy, and hence the value of such preliminary information, are completely dependent upon the caliber and practical experience of the men performing this coordination work. Certainly, they must be more than pure geologists or geophysicists, but should be a combination of both. Because of the time factor requisite to obtaining experience, these dual attributes are not apt to be found in either equal or high degree among men of junior rank.

The field geophysicist may point to the list of oil and gas fields for which he can claim credit. His pride is justified for a job well done, perchance in spite of such factors as remoteness of location, adverse climate, difficult terrane conditions and to which is usually added, poor quality of data, or complicated interpretations, or both. However, credit for the fact that his efforts terminated in positive, rather than negative results, must often be shared with geological-geophysical coordinators, whose planning and authority originated the projects. By way of example, the geophysicist finds it difficult to satisfy an oil company that is undertaking geophysical work for the first time. All of us have probably heard the discouraged words of the non-technical wildcatter who, on the basis that an exploration method must be either fully reliable or completely unreliable, decided to abandon completely a particular geophysical method, which after a trial or two had failed to produce an unequivocal result.

It can truly be stated, that the easily found structures or anomalies have been discovered already in most domestic oil provinces, so any extensive oil-finding campaign must include marginal areas in point of workability. Therefore, to obtain the highest degree of positive results in the future, the geophysicist will be more than ever dependent upon a management, which in being well informed on the attributes as well as the limitations of the various exploration methods, can supply skilled guidance, supported with patience and fortitude.

The actual conduct of the field program is no less important than its planning. Here also, mental caliber, experience and coordination of talents are of paramount importance. Key personnel are required for three functions; these are: management of the party, interpretation of geophysical data, and geologic orientation. In seismograph operations, which often attain elaborate (and expensive) proportions, separate men may be required to fill adequately these three roles. In fact, there are often field circumstances where less than three men would be expensive in terms of results. The feature of geologic orientation is particularly important, for instance, in being fully apprised at the outset regarding the geologic premise for entering the particular area, the instrumentation and computing tech-

niques can be adjusted to cope best with the anticipated problems at least as they are initially conceived. In serving as a liaison between the party chief (or seismologist) and the management-exploration staff, the geologic observer can contribute information which may indicate the proper solutions for unexpected difficulties, such as peculiar weathering situations, lack of sensitivity, unusual reflection or refraction events, *etc.* There is also the economic point, that the field program can be changed immediately as results begin to modify, or even disprove the initial hypothesis.

It is likely that petroleum will continue to be found indefinitely by reworking old areas in greater detail, or with instrumentation especially adapted to each particular problem. It is also natural to assume, that major undiscovered pools lie concealed in regions which so far have yielded an unusable variety of geophysical data. The Delaware basin of West Texas, the Michigan basin, and the Tejon Ranch area of California are prime examples for the seismograph at least. Undoubtedly, the geophysicist will find himself ever confronted with a frontier dividing workable from non-workable areas. Though he can point with justifiable pride to the distance this frontier had been pushed back to date, nevertheless, the task grows increasingly difficult. So a third unit in the exploration organization is assuming increasing importance; I refer to a liaison research and engineering department between the field and the geophysical laboratory.

Two examples from the reflection seismograph illustrate the function of this liaison department and its range of interest. First, basic field research could involve studies of sonic wave propagation with a view to accomplishing a reduction in the ratio of disturbance to reflection energy, or for improving the ability to resolve more closely spaced reflections, *et cetera;* second, engineering effort would continue to focus upon improving electrical characteristics of the recording system in terms of sensitivity, frequency discrimination, volume control action, *et cetera*. Then, there are the practical physical aspects of reduced weight of instruments, as opposed to greater ruggedness, plus increased ability to withstand extremes of temperature and humidity.

A final and equally important link in the exploration organization is the review section, wherein all forms of exploration data are consolidated. This entails the amalgamation of information from a wide variety of sources; this could include geologic interpretations from outcrops, core drilling, electrical, radioactivity, and density logs from deep wells, geochemical evidence, all combined with various geophysical reports. Here again, the personal factor is important, since the effectiveness of such review and coordinating effort is dependent on qualities of wide experience, imagination, and skill. The review section chief, located in either the district or headquarters office, should have a direct connection to exploration management, so as to have a voice in shaping the course of further exploration, or development, as the case may be. Because of this relationship, he should appreciate the importance of making a forceful presentation of data, with proper accent given to the salient features of an anomalous situation by the skillful coloring of maps having a common scale.

It follows that review work must be considered for each area as often as a new

control is added. Here is an excellent opportunity for the man with a curious and imaginative turn of mind to recast a previously indeterminate piece of geophysical evidence in the light of some new supplementary data! Certainly the resulting hypothesis could create the best lead for a fresh geophysical investigation. Without such a review section, one might say that a few oil fields are "lost" in the files.

The importance of skill, experience, and coordination of men within the exploration industry has been stressed, but there is another personnel aspect that should be considered—that is to say, the future effectiveness of the exploration industry, say ten years hence is dependent on the caliber and training of university graduates who are now entering the profession. In looking back 10 years or more, we recall that geophysical work possessed the lure and romance of a new profession, plus a compensation differential high enough above the average industrial level to overcome any hesitation. But to-day, exploration geophysics does not possess these two inducements. So, we are doing an average job of competing for desirable new personnel. I have heard the question asked, "Why should a man elect to move around in a situation of difficult housing, when he can obtain easily a position in one place in many other lines of engineering endeavor, and for about the same gross income?" Fortunately, there seems to be a growing realization that incompetence in geophysical interpretations is costly at any price, while in contrast, an alert, resourceful and experienced geophysicist can be cheap at almost any price. Three recommendations are offered:

1. Publicize exploration on industry-wide basis, so that undergraduates will have the earliest opportunity to elect geology and especially geophysics for a career.

2. Offer advice to interested universities on suitable curricula, which should stress a broad science training. Major studies should include mathematics, physics, geology, *et cetera*, with minors in chemistry, English, languages, *etc.* Laboratory work should be restricted to demonstrations of fundamental principles pertaining to the various geophysical methods.

3. Give the same assurance of future prospects to the young man whether he starts out as a geophysicist or a geologist.

Recognition of the importance of the preceding aspects of integration to effective exploration is reflected in the activities of the Society of Exploration Geophysicists.

First, I would mention the compilation of a new Cumulative Index of our journal *Geophysics*. This presents a complete list of technical articles by authors, also by subject classification, through 1947. Patents pertaining to geophysics are listed in a new section by inventors' names, also by subject, through 1946.

Second, a campaign to accumulate more than 50 geophysical case-history papers, covering a wide range of producing fields, has been successfully completed. This collection will appear next fall in Volume I of a proposed *Geophysical Case History Series*.

Third, I would make special mention of the organization to date of six local sections—first in Tulsa, then in Dallas, Houston, Shreveport, Fort Worth, and in the Los Angeles-Bakersfield area. As intimated previously, there is a need to

develop men who are competent in both geology and geophysics. Geophysicists have benefitted greatly from local section meetings and distinguished lecture tours of the A. A. P. G. If, as a consequence, the average geophysicist knows more about geology than the average geologist about geophysics, then here is our opportunity to offer recompense. The S. E. G. local sections are created at a time when exploration geophysics seems to be fast losing the aspect of secretiveness. The pooling of common knowledge and experience is started already. For instance our Los Angeles-Bakersfield section has held two symposiums to date: the first on "Multiple Reflections," and the second on "Correlation of Reflections." The Dallas section plans to present a symposium on an important topic of equal common interest at a regional meeting next fall. To stimulate interest and to further understanding of the common ground between geology and geophysics, the suggestion has been made that joint field trips should be organized and conducted by experienced geologists and geophysicists, with emphasis placed on structure and lithology, rather than upon the details of stratigraphy and nomenclature. Certainly by such collective efforts the art should progress much faster than by separated endeavors.

The interest of the Society toward inducing and preparing engineering and other undergraduates for exploration geophysics is centered in two standing committees: one for "Student Membership," and the other for "Geophysical Education." This interest has been reciprocated fully, since we can now count more than 70 student members. We can also point with pride to two newly formed student chapters—one at the University of Tulsa, with the other here at the Colorado School of Mines.

No one can deny that the exchange of ideas on instrument design, which has been carried out over the years between geophysical research men, has been of great benefit to the exploration industry. However, there is also the aspect that novel suggestions, leading to advancements of more radical character, might be derived from sources anywhere in the broad field of electronics. With this thought in mind, the S. E. G., in conjunction with the American Institute of Electrical Engineers and the Institute of Radio Engineers, is forming a liasion committee to survey the applications of electronics to exploration geophysics.

I wish to refer again to the mining specialists as I conclude this portrayal of the necessity for sharpening existing tools and coordinating the use of every kind of ability and method. It is my understanding that new discoveries are needed as badly in the mining as in the petroleum industry. On the premise that geophysical efforts must be increased in the mining industry, the Society of Exploration Geophysicists is happy to arrange at this convention a special symposium for producing an exchange of ideas between the two industries.

It is evident that exploration efforts should be united upon a single wide base instead of continuing to follow separated channels of mining and petroleum. Therefore, it is the hope of the Society that this first joint meeting with the mining specialists, which is held appropriately in Denver, will initiate a permanent working relationship for the benefit of all exploration.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1221-1226

# PETROLEUM IN EUROPEAN RECOVERY PROGRAM[1]

MAX W. BALL[2]
Washington, D. C.

The petroleum supply situation has so many aspects that to discuss all of them would require a much longer talk than I propose to make or you would care to listen to. I have therefore picked one aspect that is receiving much current consideration, namely, the amount of oil required for the European Recovery Program.

Before discussing that subject, however, I should like to give you very briefly the manner in which the Government agency I represent is concerned in it.

## OIL AND GAS DIVISION

Whenever I am introduced to an audience as the Director of the Oil and Gas Division, I can feel people wondering what the Oil and Gas Division is, what it does, and what the reasons may be for its existence. I shall therefore try to answer briefly the questions that I know are in your minds.

The Oil and Gas Division is a part of the Office of the Secretary of the Interior. Except for enforcement of the Connally Act prohibiting interstate shipment of oil produced in violation of State laws—a function kept separate and distinct from its other activities, and to which I shall not refer further—the Division is strictly a staff unit with advisory functions only.

The Division was created in May, 1946. It assists, and on occasion acts for, the Secretary of the Interior in the discharge of four duties entrusted to him by the President, as follows:

1. To act as the channel of communication between the Government and the petroleum industry and thus, so far as appropriate, to perpetuate in peace the cooperation between the industry and the Government that played such an important part in winning the war. This function is exercised in part through direct contact and consultation with the industry, but in the main through the National Petroleum Council, an 89-man body created by the Secretary of the Interior to advise the Government on petroleum matters and petroleum policy.
2. To act as the liaison agency between the Government and appropriate state bodies. This function is carried on by direct contacts with members of the various state regulatory bodies, and by non-voting membership on the Interstate Oil Compact Commission.
3. To keep the President informed of significant developments in petroleum matters, and to advise him of any steps necessary to safeguard the nation's petroleum future.
4. To coordinate, and so far as possible to unify, the administrative practices and policies of the various Government agencies with respect to oil and gas.

Some forty Government bureaus, divisions, and other agencies are concerned more or less actively in oil and gas matters. They comprise technical, research,

[1] Read before the Association at Denver, April 29, 1948.

[2] Director, Oil and Gas Division, Department of the Interior.

and statistical agencies such as the Geological Survey, the Bureau of Mines, the Bureau of Standards, and the Bureau of the Census; consuming and procurement agencies such as the Armed Services and the Bureau of Federal Supply; taxing agencies such as the Bureau of Internal Revenue; and policy-making agencies such as the State Department and the National Security Resources Board.

Each of these agencies has its own specialized interest in one or more phases of oil and gas matters. The Oil and Gas Division alone is charged with responsibility for an over-all knowledge of petroleum affairs, and of the effect of any particular action on the country's petroleum economy. The duty of the Division is to try to see that the actions of the individual agencies accord with a consistent over-all administrative policy.

This duty is discharged without authority over anyone. The Division advises, recommends, and counsels, but it does not direct or command.

An agency without authority may not be unique in Washington, though it is certainly unusual. What makes the Oil and Gas Division unique is that, having no authority, it seeks none. It is firmly committed to the belief that its field of usefulness is in advising, not in directing; that its views should prevail because they are sound, and only to the extent that they are sound, and not because of any power to impose them.

Because of this attitude, the Division has the widest opportunity to participate in the deliberations of other agencies. They know that they can seek its counsel on any petroleum problem, with complete assurance that the advice they receive will be disinterested, colored by no craving for their authority or their functions. As a result, little goes on in the Government with respect to oil and gas in which the Oil and Gas Division does not share in one way or another.

## ERP REQUIREMENTS

Among the matters in which we have thus been asked to participate is the quantity of petroleum to be exported under the European Recovery Program.

Petroleum products are, of course, a basic essential to any modern economy. They are particularly important in the rehabilitation of economies that have been wrecked or damaged. Western Europe's hope of an adequate food supply, for example, lies in increased domestic production through increased use of mechanized farm equipment. The distribution of food, there as here, is dependent in large part on petroleum-driven transportation. One of the causes of the scarcity of food in Paris last winter was lack of gasoline to fuel trucks to bring food from the farms.

Food is only one example. Adequate production and distribution of other goods is likewise dependent on adequate transportatoin, a large part of which must be propelled by gasoline or diesel fuel. Many railroads and many factories are dependent on fuel oil. Above all, without petroleum lubricants made in America, the machinery of the non-Russian world would soon come to a virtual standstill.

One of the greatest and most fundamental needs of Western Europe is fuel. To rebuild and expand its shattered economies, to care adequately for an increased population, it must have more fuel than ever before.

We tend to overlook the fact that Nature and the multiplication table keep on working whether there is war or peace, and that Western Europe has a considerably larger population to-day than it had before the storm broke in 1938. This increased population must be provided with food, clothing, shelter, and employment, and the provision of these things requires more fuel than in pre-war days.

To meet these increased fuel needs, Western Europe has the coal mines of Great Britain, France, Belgium, and western Germany: mines whose mechanization, never too adequate, has deteriorated during ten years of war and post-war steel shortages: mines that in western Germany, and to a less extent in the other countries, are manned by inadequately fed miners.

Despite these handicaps, European coal production is increasing. In planning their joint economic recovery with the help of the United States, the participating countries set themselves high targets for coal production. They are already surprisingly close to those targets, particularly in Great Brtain. No more unfair charge could be made than that the Marshall Plan countries are not trying to help themselves by building up their coal production.

To augment these indigenous coal supplies, the Recovery Program calls for shipping a considerable but diminishing tonnage of coal from the United States. To the extent that our miners are "willing and able" to work and that coal-car supply is adequate, we need fear no coal shortage in this country.

When the participating countries have done all that they can to increase their coal production, however, and have received the amounts of coal that will be shipped to them, there will still remain a large unsatisfied need for energy. Some of the participating countries are filling part of this need by increased hydroelectric development. The output of electrical energy in some of them is well above the pre-war level. In Europe as in the United States, however, hydroelectric energy can supply only a small part of the energy needs. Above all the energy that can be provided by coal and electricity, a large amount of energy must be supplied by oil.

Facing these fuel necessities, the countries that hoped to participate in the Recovery Program sat down in Paris last summer and prepared an estimate of their petroleum needs during the period that the Program was proposed to cover. They had only a short time in which to work. As nearly as I remember, their estimate was prepared in about ten days, starting from scratch. That the estimate was as good as it was is a tribute to the keenness and conscientiousness of the men who made it.

When the Paris report was received in the United States, its estimate of petroleum requirements was laid before the Interdepartmental Petroleum Committee, of which I happen to be chairman. One thing was immediately obvious,

namely, that whether or not the estimate was greater than the actual needs of the participating countries, it was greater than the ability of the world to supply. The estimated quantities of petroleum products could not be made available without impairing the economy of the United States.

Explicit in the whole plan for European recovery is a basic tenet: that the economies of Europe can not be benefited permanently by serious impairment of the economy of this country. The program depends on the continued vigor and productiveness of America. It can not be carried out, nor can a prosperous and peaceful world be envisioned thereafter, if in attempting to rebuild the economy of Western Europe we undermine our own. The question of how much oil could be supplied to the participating countries was examined in this light.

The petroleum estimates in the Paris report were subjected to searching analysis, country by country, by petroleum experts of the State Department and the Armed Services. The thoroughness and insight of this analysis would be hard to match. A mass of additional data were obtained from the participating countries, from our diplomatic representatives, from American and British companies operating abroad, and from other sources. Every ascertainable factor in the petroleum needs of each country was weighed: the greatly increased acreage tilled in England compared to pre-war days; the virtual supplanting of coal-fired ships by oil-burning vessels and the consequent increase in bunker fuel needs; the effect of the great numbers of heavy and aging trucks left in Europe by the United States Army, which now form an essential part of the transportation service; the increased intensity of cultivation and industrialization required to maintain increased populations; and numerous other factors increasing, or in some cases decreasing, the need for petroleum products. Based on these factors, the minimum petroleum needs for each country were estimated.

The result of this analysis is shown by the figures. The Paris report called for 1,190,000 barrels per day for the calendar year 1948. The analysis reduced this to 968,000 barrels per day for the fiscal year 1949—the fiscal year beginning July 1, 1948, and ending June 30, 1949. This reduction was more than the 18.7 per cent that it appears to be, because petroleum requirements increase month by month as economic activity is restored, and the revised figures were for a year beginning six months later than the Paris figures.

With the revised figures as a basis, an intensive study was made of the sources from which this amount of oil might be obtained, getting as much as possible from sources outside of the United States, so that as little as possible would need to be exported from this country. It was concluded that 515,500 barrels per day could come from non-dollar sources; that 38,000 barrels per day could come from indigenous sources within the participating countries, including the oil fields of Germany and Holland, a small production in France, and such amounts of alcohol, benzol, and other petroleum equivalents as might be produced; and that 434,000 barrels per day must come from dollar sources, including the United States, the Caribbean area, and American production in the Middle East.

These figures total 987,500 barrels per day, 2 per cent above the revised requirement figure of 968,000 barrels, to allow for refinery losses and the like.

### EFFECT ON UNITED STATES SUPPLY

Of the 434,000 barrels per day estimated as required from dollar sources, 338,400 barrels per day could, it was estimated, come from sources outside the United States. Only 95,600 barrels per day need come from this country. This is only 9.7 per cent of the total supply for the European countries.

How much of a hole does this make in supply available to American citizens, and how does it compare with what we have been exporting to the participating countries?

The 95,600 barrels per day is only 1.5 per cent of the anticipated supply of the United States, including both domestic production and imports.

Last year—1947—we exported 150,000 barrels per day to the participating countries. The anticipated export to these countries for fiscal year 1949 is nearly 55,000 barrels per day below 1947, a reduction of more than 36 per cent.

Exports this year have already been scaled down below the 1947 figures, and are running at about the level proposed in the European Recovery Program.

Thus, less petroleum will be shipped from the United States to the participating countries under ERP than we have been shipping to them. Widespread statements have been made that the European Recovery Program contemplates depriving American citizens of petroleum products that have heretofore been available to them. Such statements are without foundation.

It may be well at this point to dispose of another fallacy or two. The charge has been made that the European Recovery Plan proposes to take better care of the needs of other peoples than of our own, and to keep Europeans warm while Americans go cold. Also the charge has been made that ERP proposes to provide for a wholesale conversion from coal to oil. These charges have no basis in fact.

All of the participating European countries that were belligerents have been practicing rigid economy in the use of petroleum, and these economies will of course be continued. Except for a comparatively small amount used for kerosene stoves, space heating with fuel oil is virtually unknown in Europe. The oil sent to the participating countries, whether from the United States or from other sources, will not be used to provide European countries with the blessings of automatic heat.

Petroleum exports under ERP will in the main be lubricating oils and greases, for which the non-Russian world depends largely on the United States; waxes, asphalts, and other specialty products; aviation gasoline, for which the United States has most of the world's manufacturing facilities; a small amount of crude oil required by refineries not equipped to process the heavier crudes of the Middle East and the Caribbean area; and a modest amount of gasoline for essential motor transportation.

In the former belligerent countries the driving of automobiles is restricted

more severely than under our most stringent war-time rationing. Only two participating countries—Switzerland and Portugal, both of which were neutral during the war—have no restrictions on the use of petroleum products. The amount that is proposed to be furnished to these two countries is not what they have been using, but what they will need if they practice the same rigid economy that is practiced by the other Western European countries.

Despite increased dependence on motor transport, the requirements of the participating countries for motor gasoline are expected to be 16 per cent below 1938, although consumption in the United States has increased 64 per cent during that time. The amounts of all products proposed to be furnished to participating countries are less than one-tenth of the amount per capita consumed in the United States.

Finally, even the modest amounts that have been scheduled under the Recovery Program will not be furnished except to the extent that the need therefor is clearly shown. These needs will be subjected to a double screening. The Economic Cooperation Administration will scrutinize every request for petroleum products and approve only those for which essential need can be demonstrated. Then, if the products are to come from the United States, they can not be exported without a license granted, at his discretion, by the Secretary of Commerce. If the Administrator of Economic Cooperation thinks a shipment should be made and the Secretary of Commerce thinks it should not, the final decision will have to be made by the President himself. We need not worry, therefore, that any shortage in the United States will be due to increased or reckless exports of petroleum products.

No exports under the European Recovery Program will go to Russia or Russia's satellites, despite newspaper and radio reports to the contrary. The law confines deliveries under the Program to participating countries, and Russia and her satellites have vigorously excluded themselves from participation.

It is possible, perhaps even probable, that we will have local gasoline shortages this summer, particularly in the Middle West. Local shortages of fuel oil may again afflict the Eastern Seaboard and the North-Central States next winter. The extent and severity of such shortages will depend on a number of unpredictable factors: what kind of weather we have; whether we have strikes; whether we have disasters such as that at Texas City; the extent of increase in military demands; and perhaps above all, whether the public is saving or reckless in its use of petroleum products. But if such shortages come, they will not have been caused by increased exports under the European Recovery Program.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1227-1264, 4 FIGS., 3 TABLES

# ARTESIAN SALT FORMATIONS[1]

BAILEY WILLIS[2]
Palo Alto, California

## ABSTRACT

This paper presents a study of the salt domes of the Gulf states, on the basis of printed information and personal communications from geologists of the American Association of Petroleum Geologists, as interpreted by the writer. The concentration of salt is attributed to evaporation of inland seas, chiefly during Permian time, when an arid climate prevailed in the interior of North America. The causes of aridity are discussed. Actual occurrences of salt brines are described.

In the theoretical discussion the origin and the mechanics of domes are considered as explained by the prevailing hypothesis of sedimentary origin, the Sedimentary hypothesis, and by an Artesian hypothesis. The latter substitutes artesian flow for load mechanics as the cause of development of domes and appeals to atomic forces for the growth of the structures. Any salt dome is hypothetically regarded as an intrusive mass, which receives additions to its volume, molecule by molecule, from brines that rise from warmer to cooler horizons and reach the saturation point. The force of growing crystals is regarded as the cause of upthrust of the dome and of the crushing of the salt itself. The presence of anhydrite is explained as due to crystallization in the order of insolubility, whereas the absence of potash salts is caused by their greater solubility. The article in general invites discussion of some old ideas and offers some additional suggestions.

## INTRODUCTION

The remarkable accumulations of salt which occur as intrusions in the sedimentary formations beneath the Coastal Plain of the Gulf of Mexico have been objects of speculation for more than half a century and various causes have been considered to account for them. In 1926, E. DeGolyer summed up the several explanations so adequately that it is not necessary to review them here, but in the score of years elapsed since he wrote so much information has accumulated regarding their distribution and nature that a further study may be pertinent. In 1944, during a tour under the auspices of the American Association of Petroleum Geologists, the writer became acquainted with the opinion which prevailed among them to the effect that the salt had been concentrated from oceanic waters by evaporation from a coastal lagoon and had been squeezed up through fissures by the load of overlying sediments. He found it difficult to fit the assumed conditions into the geographical and climatic environment of the Gulf and came to think that the agency of artesian waters offered a more promising solution of the problem of concentration and intrusion, as suggested by G. D. Harris in 1907. In the discussion which ensued he has been generously aided by well informed experts of the Association, who have placed their resources at his disposal and have contributed facts ascertained by deep drilling and by gravity surveys. He is especially indebted to C. L. Moody, editor of the *Bulletin*, to Sidney A. Judson, L. L. Nettleton, and Paul Weaver of Houston, and to Roy T. Hazzard and W. C. Spooner of Shreveport. They have not only supplied data not otherwise available to the writer, but have also assisted him by vigorous criticism of the Artesian suggestion.

[1] Manuscript received, March 30, 1948.

[2] Stanford University.

The result has been to develop an hypothesis which embodies some concepts of the prevailing explanation, including possibly the oceanic origin of some of the salt, and also recognition of the effect of load in squeezing up the salt in domes. On the other hand, the Artesian suggestion is strengthened by the probability that deeply circulating brines have been enriched by solution of buried salt deposits.

The two hypotheses, the Sedimentary and the Artesian, are thus found to be supplenentary rather than opposed. Their relations are brought out in the following discussion.

## HISTORICAL

The occurrence of large masses of common salt, crystalline NaCl, embedded in strata of the Gulf Coastal Plain and in the Permian basin of western Texas, as also the fact of similar deposits in Germany and elsewhere, has given rise to the formulation of various theories of their formation. As early as 1860, appeal was made to volcanic emanations; later in this country as well as in Germany the accumulations of salt were attributed to some structural condition, such as an anticline; then R. T. Hill[3] (1902) suggested that they are:

> the resultant products of columns of hot saline waters which have ascended, under hydrostatic pressure, at points along lines of structural weakness.

Hill had struck a reasonable trail of speculation which was followed up by G. D. Harris[4] in 1907. He added a definite element in attributing the transportation of the salt to artesian waters. Since he clearly stated the conditions governing the deposition of the crystalline salt from artesian solutions and anticipated the present writer's interpretation by 40 years, he is here quoted as follows. Referring to a map of the then known fault lines of the Gulf Coastal Plain, he says:

> By inspecting the accompanying map the reader will doubtless convince himself that if all the faults in the beds beneath the Tertiary were located, domes would be found to occur mainly at the crossings of such fault lines. The crossing of these lines naturally determines a point of weakness that would be utilized by any gaseous or liquid substance under pressure from below, seeking relief upwards. . . .
>
> The dip of the strata in the Mississippi Embayment area suggests artesian conditions along the Gulf coast. There is no reason why waters entering the pervious layers far up country should not go down to greater and greater depths as the latitude of the Gulf border is approached. Such waters might reach considerable depths, be raised accordingly to high temperature, and take into solution many salts, especially chloride of sodium. Ascending under hydrostatic pressure at the above mentioned points of weakness and cooling normally at the rate of 1 degree Centigrade for every 90 feet of ascent, a point would be reached where the solution, if saturated at high temperature, could no longer retain all its salts.
>
> With precipitation would go naturally crystallization. The power exerted by growing

[3] Robert T. Hill, "The Beaumont Oil Field, with Notes on the Other Oil Fields of the Texas Region," *Franklin Inst.*, Vol. 154 (1902), pp. 273–74.

[4] G. D. Harris, "Rock Salt in Louisiana and East Texas," *Econ. Geol.*, Vol. 4 (1907), pp. 21 *et seq.*

crystals, in general, may be assumed to be of the same order of magnitude as the crushing strength of the crystals themselves. (Day and Becker: Washington Academy of Sciences, Pro. Vol. VII, p. 288, 1905). We have subjected a 4″ cube of rock salt to a pressure of 50,000 pounds without even cracking it. Tournaire crushed cubic centimeters of rock salt with pressures of 332 to 461 kilograms (53,300 to 71,700 pounds per sq. inch). If the specific gravity of Quaternary clays and sands be taken at 2.4, then growing crystals of salt could lift 3,000 to 4,000 and even 5,000 feet of such incoherent strata.

Harris was aware that he had not up to this point suggested an adequate source for the very large quantities of salt concentrated in the domes. On this subject he says,[5] however:

> So far as the writers can judge the comparatively thin, but widely extended salt deposits of the world are . . . the result of salt pan evaporation. If, however, the salt is at a very great depth, yet subjected to the dissolving power of artesian waters, such waters being necessarily hot at the depths postulated, then the resulting solutions, if saturated at such high temperatures, are obliged to part with their salts as the surface is approached. Growing crystalline masses result. Dome structures follow.

Thus Hill and Harris had suggested a number of conditions which might reasonably result in the accumulation of bodies of salt by fractional crystallization. They are: deposition from rising solutions (Hill); solution of salts in the depths by artesian waters; rise through weak lines of faulting; occurrence of the salt in hypothetical, buried salt pans; and the precipitation in crystalline masses and the work of doming by the forces of crystallization (Harris).

The Committee[6] states that it is generally believed that the salt which constitutes the domes flows upward from a thick bed of sedimentary salt of marine origin, which is continuous over the area in which the domes occur. The writer has doubted the assumption of sedimentary salt in the Gulf region, but on investigating the evidence of aridity during the Permian and of the occurrence of redbeds and salt in Arkansas and northern Louisiana, he finds it to be confirmed, in some degree. But he thinks that estimates of the thickness of sedimentary salt should be less excessive and that deposition was in inland seas rather than in marine lagoons. He considers that Harris was right in postulating the crystallization of the salt from artesian waters, and he goes a step further in suggesting that much of the salt itself was brought in by those waters from the surrounding watershed.

Statements of the two hypotheses are given in Table I, in parallel columns for ready comparison, and more *in extenso* in the following pages.

[5] G. D. Harris, *op. cit.*, p. 33.

[6] Upon receipt of the original draft of the article, "Artesian Salt," the editor referred it in usual course to a committee of censors, consisting of Sidney A. Judson, L. L. Nettleton, M. A. Hanna, Paul Weaver, and Albert G. Wolf. The discussion which followed has led the writer to modify and expand the statement of the Artesian hypothesis to its present form. The Committee having referred to a generally accepted theory of the salt domes, the writer requested that it be definitely stated in order that it might be discussed along with the Artesian concept. The Committee courteously complied and the "generally accepted theory" is included herewith.

TABLE I

STATEMENT OF THE TWO HYPOTHESES

| *Sedimentary Salt* | *Artesian Salt* |
|---|---|
| The salt was presumably concentrated by evaporation of sea water. The environment of a marine lagoon is implied but not described. The stratum of salt produced is thought to have underlain the entire area beneath the salt domes. | The salt was concentrated in artesian brines. Some part of it was probably derived by solution from sedimentary deposits that gathered in inland seas, possibly in marine lagoons. The balance, more or less, diffused and gravitated from descending surface waters into warm, deep brines. |
| It is assumed that salt will flow under an adequate load like a viscous fluid and that the load of super-incumbent strata has caused it thus to flow upward through structural openings in such a manner that it has assumed the form of subcircular domes and plugs. | It is assumed that conditions favorable for artesian circulation have existed in strata at or below the general horizon of the bases of the salt domes and that the brines circulated very slowly under hydrostatic pressure upward along structural fissures to cooler levels; the cooling caused the salt to crystallize out wherever a film of the brine could penetrate, as in bedding planes, joints, and faults. |
| The volume of any dome or plug thus forced up through the overlying strata would depend on the thickness of the bed of salt and the area from which salt might flow toward the opening. The upward thrust would displace the strata, lifting and pushing them aside, mechanically, the resulting form being that which would develop the least resistance. | The volume of any body of salt thus crystallized from solution would depend upon the salinity of the original brine and the change of temperature, and upon the persistence of the process during ages. The growth of the crystalline mass would be like that of a tree, outward and upward. The atomic forces would add molecule on molecule, exerting pressure against the surrounding rock and also upon the body of salt. |
| It is argued in favor of this hypothesis that it explains certain structural features of the salt domes, viz.: (a), the rounded forms; (b), the thinning of sediments over domes because of uplift contemporaneous with deposition; (c), the thickening of sediments in the area peripheral to the domes, caused by sinking of the surrounding area from flow of the salt into the dome. Thus, the "rim syncline" sediments are lower and thicker than in contemporaneous deposition away from the domes. | The several mechanical effects produced by the growth of a dome upward through a thickness of strata upon which additional sediments are being deposited are not peculiar to the intrusion of salt as a viscous fluid. They follow as cogently from the upthrust of a salt dome as caused by the growth of the crystalline mass from artesian brines. |

*Generally accepted hypothesis.*—The hypothesis of the origin of the salt-dome salt and the manner of development of the domes is stated by S. A. Judson for the Committee, as of August 14, 1947.

1. The salt flows upward into domes from a thick bed of sedimentary salt which is continuous over the areas in which domes occur. Actual evidence from drilling into this salt layer between domes is lacking, but numerous wells have been drilled in the marginal areas of salt basins and have found salt with chemical constituents similar to those of the domes. From drilling areas marginal to the North Louisiana and East Texas salt dome basins, the salt layer is around 1,000 feet thick. A minimum thickness of around 1,000 feet is derived from gravity data in certain parts of the Gulf Coast salt dome basin. It is presumed that the salt layer was deposited by evaporation of sea water.

2. The salt flows primarily because of the instability resulting from a low density layer being under a higher density one. The relatively low density of salt is firmly established

from sample measurements and by gravity surveys. It is assumed that salt and sediments through long periods of time flow in a manner similar to that expected of highly viscous liquids.

3. The locations of individual domes may be caused by structural movement or by inhomogeneities in the overburden; a relatively small irregularity may cause an incipient movement which, once started, proceeds because the motive force to cause the movement increases as the dome rises. Probably the dome, once started, takes its form with relatively little further influence by the initiating disturbance.

4. Natural consequences of the flow of salt through long geologic time are:

(a) The rounded forms of the domes as would be expected of flowage; the form is that which would have minimum resistance for a given volume and height.

(b) Thinning of sediments over domes because of uplift contemporaneous with deposition.

(c) Thickening of sediments in the area peripheral to the domes, caused by sinking of the surrounding area from flow of salt into the dome. Thus in the "rim syncline" sediments are lower and thicker than in contemporaneous deposition away from the dome.

In the Gulf Coast the regional geology is very simple (monoclinal dip toward the coast), extensive drilling has been done around domes, and detailed subsurface studies made by use of paleontology and electric logs. This work has clearly established the three conditions, (a), (b), and (c), in many instances, and they may be considered typical and diagnostic criteria of domes formed by buoyant flow.

*Artesian Salt hypothesis.*—The hypothesis here proposed to account for the concentrations of salt in the domes of the Gulf region (but not necessarily for salt deposits in all such formations) postulates that the salt has been brought by rivers and ground waters to the artesian basin of the Gulf and has crystallized in the domes from warm brines as they rose in the artesian circulation to cooler horizons. This follows Harris' reasoning, but the argument is developed in accordance with the growing knowledge of the underground conditions.

The existence of an artesian hydraulic head in Tertiary strata of the Gulf region has long been demonstrated by many wells. In the latitute of the Gulf Coast the drill has not penetrated to the more deeply buried Mesozoic formations, but the basin-like structure extends to the bottom of the series, which is practically conformable, that is, devoid of tectonic disturbance, throughout.

The hydraulic head means that permeable strata, into which surface waters percolate and which they follow down, are sealed at the bottom, at least so that the volume of escaping waters is less than that of those that enter. Where, as in the Gulf, sediments are distributed by waves, shore currents and ocean currents, the cleaner sands are in general spread upon the continental shelf, the finer are sorted out and settle in deeper water. The two occur more or less interbedded in the thick piles of strata and they grade into one another. Particularly do the sands which are relatively permeable, finger out into impermeable silts in such a manner that they are closed along and around the lower edge of any lens. Waters that have percolated down in the pores between the sands thus come to fill a pocket and stand under the hydraulic head of their depths below the outcrop. When

such a body of water is tapped by the drill it rises in the hole, as in an artesian well.[7]

Numerous artesian wells have been drilled in the Gulf region and the condition is clearly recognized as one of common occurrence in the sequence of Tertiary strata penetrated in drilling, down at least to 10,000 feet, more or less. It is here assumed that similar conditions, more or less favorable, occur in the underlying formations, which were deposited under similar geographic conditions in the same, subsiding basin. The earliest permeable horizon that can be identified is the base of the Permian, the Eagle Mills formation of northern Louisiana. It represents a northward advance of the shore from some more southerly position, which remains unknown because the horizon lies below the deepest drilling.

Marine sediments retain sea water, connate water which has an average salinity of 36 per thousand. As they subside and accumulate in such a basin as the Gulf the temperature is gradually raised to that of the depth reached. Observations in deep wells, compiled by Earl A. Nichols,[8] show that the isotherms follow irregular courses, in detail, but in general in the Gulf region contour the depression and indicate a temperature of approximately 250°F., 120°C., at a depth of 10,000 feet. Any standing or slowly moving waters carried down with a subsiding stratum would attain that temperature and according to the laws of physical chemistry their potential capacity to dissolve salt would be increased from approximately 3,600 grams per liter at 50°C. to about 4,200 grams per liter at 120°C.[9] Salt would migrate accordingly by diffusion in the effort to maintain equilibrium of solution.

As artesian circulation was established diffusion would continue to operate in slow-moving or stagnant waters in the depths, but would be ineffective at higher levels, where dilute surface waters circulated more freely. Any contribution to the deep brines must therefore come from waters percolating down in more deeply buried strata; furthermore, such waters must have a salinity higher than that of the brines, or the migration of salt would be reversed. It follows that there must be sources of salt, presumably salt beds, the solution of which would result in stronger brines.

We are thus returned to the assumption made by Hill, Harris, and later advocates of the existence of sedimentary, saline formations below the level of the bases of the domes, but with the alternative postulate that the salt may not occur directly beneath them. It may have been distributed anywhere up the slope in the path of descending waters. The concentration of salt by evaporation in the Permian basins of West Texas points definitely to the existence of similar conditions

[7] For the definition of "artesian," "artesian pressure," "artesian basin," *et cetera*, as here used, see M. L. Fuller, "Underground Water Papers, 1906," *U. S. Geol. Survey Water-Supply Paper 160* (1906), p. 14.

[8] Earl A. Nichols, "Geothermal Gradients in Mid-Continent and Gulf Coast Oil Fields," *Amer. Inst. Min. Met. Eng. Petrol. Div.* (1946).

[9] *Tables of Natural Constants*, solubility of sodium chloride.

of the same age on the Gulf watershed and this inference is confirmed by the occurrence of the Louann salt in Arkansas and northern Louisiana.

There remains, however, one difference between the salt deposits of West Texas and the salt of the domes, as pointed out by Paul Weaver.[10] The latter are pure NaCl; there are no deposits of potash, such as normally occur among the products of evaporation. They are therefore not *normal* products of evaporation, or were not thus deposited.

Whatever salinity the waters may acquire, short of saturation, they will dissolve more salt wherever it may be available. If beds of salt were buried in the strata through which waters percolate, the salinity will be increased and the heavier solution will gravitate toward the depths. This is a gradual process, as all these changes are, but it would result in strong brines in the course of time. The degree of salinity in the Black Sea or the Dead Sea has been attained since the passing of the latest glaciation and its attendant humid climate during some five thousand to ten thousand years; the ages since artesian conditions were initiated are measured in tens of millions.

We have been considering a general process that must have worked very unequally in different parts of the Gulf basin in view of the diversity of the conditions. It is assumed that relatively strong brines accumulated in the depths. With the gradual or sudden development of structural features, joints, faults, or slides, the relatively static condition would be disturbed. The brines would rise under hydraulic head and on reaching cooler levels would attain saturation and deposit crystalline salt.

The salt, crystallizing from the saturated solution, would intrude between strata along bedding planes or into joints and fissures of any kind. The liquid solution would exert a pressure equal to the hydrostatic head and would be drawn in by atomic attraction. The salt in crystallizing would gather molecule after molecule with the atomic force of the union of atoms of sodium and chlorine. The salt layer or plug must grow as long as the solution of the appropriate strength flows up and the resulting body of salt may be expected to take the form that meets with least resistance. The outer surface of any dome or plug would offer the film where penetrating solutions would intrude most forcibly and the salt body would increase by the addition of concentric layers. Multiplying and growing in the confined space the crystals exert atomic force. They push up the strata and crush the salt, as is shown by the respective structures. The action of the crushing stress is clearly demonstrated by the shearing of the salt and by the normal faulting of the rock envelope.[11] The stress is also expressed in folding of the strata where they are pushed aside.

The rounded form of domes, the thinning of sediments over the dome, the "rim syncline," and the thickening of sediments in the peripheral area, all follow as re-

[10] Personal communication.

[11] See Development of Salt Domes, p. 1251.

sults of this process. The criteria enumerated as (a), (b), and (c), in confirmation of the Sedimentary theory, are equally consistent with the Artesian theory.

The development of a salt dome according to each of the hypotheses is discussed in subsequent pages, following the presentation of certain pertinent facts.

## ACTUAL OCCURRENCES

Before proceeding to the more detailed discussion of the relative merits of the two hypotheses offered to account for the concentrations of salt in the salt domes of the Gulf it seems desirable to describe several instances of saline waters other than those of the ocean, which actually occur to-day and have been studied in more or less detail.

*Karabughaz Gulf.*—The type of a shallow salt bay or lagoon is Karabughaz Gulf, an embayment on the eastern side of the Caspian Sea. It is approximately 100 miles in diameter, 1–12 meters deep, and is separated from the Caspian by a sand bar, that almost cuts it off. The opening is only 100–150 meters wide. It is maintained by a current from the Caspian into Karabughaz, caused by evaporation from the latter water surface. There is no reversal of the flow at any season and the salts brought in constantly add to the salinity of the shallow waters of the bay. The salinity of the Caspian is but 13 grams per liter, or 13 per thousand, in general; that of Karabughaz, 28 per thousand. While calcium salts are deposited around the margin of the bay, where there is presumably some infiltration of fresher water through the sands, sodium chloride and sulphate are precipitated from the more saline offshore waters. The Caspian and Karabughaz lie in the western margin of the desert steppe of northwestern Asia. The rainfall increases from 10 to 14 inches or more toward the west, but there is only scanty vegetation of xerophytic character.

This example of a shallow, inland sea merely illustrates the fact that evaporation in excess of precipitation may cause a current from one body of water to another and may produce an increase of salinity in the latter.

In the Caspian Sea itself the salinity of the surface waters is reduced by the Volga and other rivers, but the effect of evaporation is such that below some 300 meters there is a body of heavy water that is without oxygen and lifeless. Thus the Caspian presents the example of an enclosed sea which is constantly receiving salts from relatively fresh waters and retains them in the depths by diffusion and gravity.

*Dead Sea.*—The Dead Sea in Palestine represents an example similar to Karabughaz Gulf; there is an inflowing stream of moderate salinity, the Jordan, and concentration of the solution by evaporation, but with the added condition of great depth. As the waters gain in salinity they become heavier and sink. There results an adjustment to density, sometimes described as a density stratification. Grabau[12] gives an account of the salinity of the Jordan as 1.61 per thousand, in-

[12] A. W. Grabau, *Geology of the Non-Metallic Mineral Deposits*, Vol. 1 (1920), "Principles of Salt Deposition," pp. 195–99.

creasing to 7.7 per thousand near Jericho. That of the Dead Sea ranges normally from 192.153 at the surface to 259.980 at 300 meters below the surface. Hazzard, Spooner, and Blanpied give some additional information,[13] and say:

> Salinities of the Dead Sea waters plotted against depths in feet between limits of 140 and 985 feet gave a straight line relationship on semi-log paper [which] indicates that the Dead Sea waters are sufficiently static below a depth of 140 feet to allow the development of a density stratification.

They note the dependence on temperature, but as no temperature data are available for the deep Dead Sea waters, that influence can not be evaluated.

Grabau notes that the waters of the lower Jordan have a high, complex salinity because of the occurrence of older beds of rock salt in the watershed, but they nevertheless contribute nearly pure chlorides to the Dead Sea in consequence of precipitation of the carbonates and sulphates as they enter the sea. It is worthwhile to call attention to this effect of fractional crystallization in a large waterbody as a process which may in part account for the purity of rock salt, especially where the latter has had a complex history of repeated solution and recrystallization.

*Black Sea.*—A similar case is presented by the Black Sea except that there is an inflow of strongly saline waters in a current that sinks and thus directly contributes to the heavy mass. The conditions have been carefully determined by Russian observers[14] and may be summarized with advantage.

The area of the Black Sea is about 164,000 square miles, nearly equal to a third of Texas. The maximum depth is a little more than 6,000 feet. The large volume of fresh waters contributed by the great rivers of western Russia spreads over the surface as a layer approximately 200 meters thick, in which there are seasonal changes of temperature and convection currents. Beneath the surface layer lies a body of heavy water about 2,000 meters deep, which fills the basin and appears to be stagnant. The contact between the surface water and the deep mass is not level, however, but is dome-shaped, being nearer the surface out from the shores and depressed along them. The curves of isotherms and isohalines (contours of equal salinity) conform to this doming down to 200 meters, but flatten out below. In March the temperature between 100 meters and 150 meters in depth is 8.5°C. (47.3°F.) and the salinity is 20.5 per thousand, the two curves lying close together and parallel. The close relation of temperature and salinity is shown in the graphs down to 300 meters, where the salt content is 21.5 per thousand. Thence it increases very slowly to 22.5 at 2,000 meters. The bottom temperature is 8.9° C. (48°F.). The differences are slight, but positive.

The Black Sea thus appears to present an example of close adjustment of salinity to depth and temperature in a very large and deep water body, and that,

[13] "Notes on the Stratigraphy of the Formations Which Underlie the Smackover Limestone," *Shreveport Geol. Soc. 1945 Reference Report*, p. 498.

[14] J. Shokalsi and N. Nitikin, "L'Océanographie de la Mer Noire," *Annales de Geographie*, Vol. 36 (1927), pp. 385–400.

to a certain extent, is the fact. But there is an adventitious condition which increases the salinity of the deeper waters in particular and presumably affects that of the whole sea. This is the inflow of highly saline waters from the Mediterranean by a current that comes up the Bosphorus along the bottom of the channel. It carries the salinity of the eastern Mediterranean, about 38.5 per thousand, enters the Black Sea at the head of the Bosphorus under the outflowing current, over a sill at 30–90 meters depth, and sinks. One might expect it to produce a well defined stratum of heavy water on the bottom of the sea; instead the salt appears to diffuse into the great mass of less saline water and the volume of water that it contributes undoubtedly raises the level of the discharge.

This anomalous condition is attributed to evaporation from the surface of the sea, but it is difficult to see how evaporation would induce a current from the Mediterranean so long as there is an opposed hydraulic head due to the higher level of the sea. The outflowing current demonstrates that there actually is such a head, while the inflowing under-current shows that the level of the sill over which it enters is below sea-level of the Mediterranean. An explanation may be found in changes of level and climate. The entire area of the Aegean has subsided during Pleistocene time and, in a geological sense, recently. When the land stood higher the Bosphorus was a normal river, which cut a canyon, the Bosphorus, from the Black Sea to the Sea of Marmora. As subsidence carried that channel below the level of the Mediterranean, the heavier waters crept up it and floated the lighter outflowing stream, bringing about the actual relation. As the subsidence continues, a stage may be reached when the surface levels would be the same and eventually the Black Sea will have the relation to the Mediterranean which the Adriatic now has. The relative salinities will then depend on any excess of evaporation over precipitation, or the reverse.

Climatic changes in Europe have been very marked during the last twenty thousand years. When glaciers were extensive the Mediterranean occupied the relative position with regard to an ice blanket that is now that of Baffins Bay. The southern lands of Europe, the Mediterranean itself, and northern Africa received heavy rains and evaporation was low. The salinity of the Mediterranean may well have been like that of the North Atlantic, approximately 35 per thousand. It is now 38–39 per thousand. The Black Sea has experienced similar changes. In their bearing on the discussion of possible salinity in any particular case, they call attention to the importance of the time factor.

*River flood plains. The Chaco, Argentina.*—Where rivers are heavily loaded with sediment, as the lower Mississippi is, they build up their banks above the adjacent flood plain with the result that their waters seep through the elevated banks and rise in the plain, where they evaporate and deposit salts. If the conditions are seasonal and rainfall in the wet season is copious the salt is washed away; but if rainfall is scanty it accumulates and salt pans develop outside of the high banks. An example of this occurrence came to the writer's notice in northwestern Argentina and adjacent areas, in the Gran Chaco, and he was struck

with the accumulation of brine that had developed in surface and underground waters. There is no fresh water except in some of the rivers themselves.

The Gran Chaco is part of a wide flat in the interior of South America, an interior, subsiding depression, between the foothills of the Andes and the Parana River. Rivers flow from the mountains eastward and across the north-south climatic belts from aridity to humidity, from desert height to forested lowlands. The broad basin has been deepening and filling during at least Pleistocene time. Salt pans border the streams all across the alluvial flats and the rivers become strongly saline wherever they break through their banks. As they have meandered widely and constantly, the whole area has become charged with salt. The process has been going on during the filling of the basin with alluvial deposits and the salinity extends to great depths.

### GULF OF MEXICO

The preceding examples have been described in the endeavor to throw light on the conditions that may have operated to concentrate salt in the Gulf area. It is apparent that the geography of the Gulf and the changes of climate are, and have been, of critical significance.

The actual Gulf of Mexico is a basin bounded by Florida, Cuba, Yucatan, and Mexico. The lands that now delimit it are of different ages as lands and of unlike geologic histories. Florida is apparently a southern peninsula of the ancient continental element, Appalachia. Cuba, Yucatan, and Mexico are all very young, relatively, and so far as is known owe their present extent chiefly to late Mesozoic, Tertiary, and Quaternary activities. The bottom of the Gulf is a slightly concave area, which lies at 1,500 to 3,000 fathoms below sea-level, in oceanic depths. It may logically be regarded as an embayment of the Atlantic basin, from which it has been separated by the uptrusion of the Peninsula of Florida.

Schuchert presents the view that the depression now occupied by the Gulf is the result of subsidence which began in Middle Cretaceous time. Prior to that hypothetical subsidence he supposes the area to have been a flat "plate," occasionally crossed by "geosynclinal seas."[15] He was greatly influenced by German theories of continental foundering and was himself a disciple of Edouard Suess, who conceived the hypothetical Gondwana continent. It was supposed to have stretched from South America across the Atlantic, Africa, and the Indian Ocean to India and beyond. In 1931–1932, Schuchert modified his ideas as expressed in his article on Gondwana landbridges, and it may be supposed that he would have changed them in regard to the existence of an Antillean continental area had he revised his work on the historical geology of that region. The disappearance of the hypothetical Antillean continent is placed by Schuchert in the late Cretace-

[15] Charles Schuchert, "Gondwana Landbridges," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 875–982, spec. pp. 887–89.
———, *Historical Geology of the Antillean-Caribbean Region* (1935), Preface, pp. vii–viii, and pp. 33–41.

ous. In contrast to his published views, the writer is of the opinion that the depression of the Gulf of Mexico was a part of the western Atlantic basin until separated from it by the development of the Peninsula of Florida and has never been a shallow sea or land area.

The problem may be tested by seismological evidence which enables us to discriminate between sub-oceanic basements and continental shields, the transmission of earthquake waves being faster in the former. For instance, under the Pacific the velocity is 4.4 kilometers per second more or less, as against approximately 3.6 in the continental complex. In the western Atlantic between the continental shelf of North America and the Atlantic median ridge, the velocity is again 4.4, as in the Pacific. In the eastern Atlantic it is lower and the presence of continental layers is inferred.[16]

Gutenberg[17] states under current date that the velocity of seismic waves across the Gulf is not known, but that reflections of them render it probable that there are no continental layers of appreciable thickness. So far as this information goes, it indicates an oceanic character for the Gulf.

## PAST CLIMATES AND STRATIGRAPHY

The concentration of salt by evaporation requires an arid or semi-arid climate, one in which the rainfall is not sufficient to dissolve and carry off the salt that otherwise may accumulate. The presence of sedimentary deposits of salt, interbedded with sediments, as in West Texas, is strong evidence of the dry climate that reigned there in Permian time. It directs attention to the conditions of climate that may have helped to concentrate the salt of the domes in the Gulf region. We may go back to the Permian and review the changes that followed through Cretaceous and Tertiary periods.

*Permian to Jurassic climates.*—The Permian was a period of very unusual climatic conditions the world over. The southern continents were heavily glaciated, to a degree that suggests general, worldwide refrigeration. The northern hemisphere, nevertheless, by contrast, was warm. The difference was probably due to the flow of ocean currents. Land connections between South America, Africa, and the East shut off equatorial currents from the southern oceans, while a continuous equatorial stream of great width and volume circulated clear around the world and back through the Arctic.[18] It came across southern Asia and Europe into the Atlantic and turned to the southwest to pass between North and South America. But the northern margin of it hit the coast north of Florida and turned

[16] Beno Gutenberg and C. F. Richter, "Seismicity of the Earth," *Geol. Soc. America Spec. Paper 34* (1941), p. 73 and map, p. 74.
Jean-Pierre Rothe, "Quelques Aspects de la Structure Terrestre Éclairés par la Sismologie," *Revue Scientifique*, No. 3271 (15 Avril, 1947).

[17] Personal communication.

[18] Bailey Willis, "Isthmian Links," *Bull. Geol. Soc. America*, Vol. 43 (1932), pp. 875–972, map, Pl. 29.

northeastward along it. The atmosphere of the North Atlantic must have been warm and humid, like that of the East Indies. However, the Appalachian Mountains were presumably still high enough to rob the northeast trades of their moisture, as the ranges of eastern Australia now deplete similar winds.

The contrast with the present humidity in the interior of North America was increased by the absence of the Arctic icecap. The pressure of the heavy, cold air which now forces the storm track of the westerlies south into the United States could not have been equally effective or was presumably replaced by law barometer over the warm Arctic sea. The interior was apparently a desert, especially arid in the south and southwest. The Gulf Coast shifted back and forth across the Gulf states and the climatic conditions along it may have resembled those that now exist in the desert lowland north of the Great Bight of the south coast of Australia.[19] But in the north the climate may be supposed to have been warm, temperate, and humid, and large rivers flowed south into the desert, even as the Nile enters the Sahara. One may surmise that the watershed which is now drained by the Missouri was in part steppe country, in part plains with swamps and shallow lakes, sloping in a wide belt of flats to the southeast, south, and southwest. The red sediments of the Permian, Triassic, and Jurassic are variable, lenticular, and cross-bedded to a degree that clearly indicates shallow seas and muddy currents, shifting over wide flat expanses. There presumably were salt seas, like the Caspian and Black Sea, where surface waters were fresh, but brine gathered in the deeper waters. Anaerobic bacteria swarmed in quiet waters and deposited the black ferrous oxide that is now oxidized to ferric and paints the rocks red or brown.

The characteristic red sediments fill the basins of West Texas, west of the Llano uplift, and were no doubt derived from the general region of the Great Plains and Rockies of that time. East of the Llano uplift the Cretaceous formations obscure any older deposits and they have not been known on the Gulf watershed until discovered by the drill. In northern Louisiana and Arkansas deep wells have penetrated redbeds and salt in stratigraphic relations that were assigned to the Jurassic by R. W. Imlay, but are now placed in the Permian by Roy T. Hazzard, W. C. Spooner, and B. W. Blanpied.[20] The two correlations are shown in Table II.

In this discussion we follow Hazzard's classification, except that "Eagle Mills" is interpreted to include Werner anhydrite and Louann salt, as stated by Imlay.

Imlay[21] gives the following description of the paleogeography of Arkansas during the Mesozoic:

[19] T. A. Blair, *Climatology, General and Regional* (1942), pp. 452, 461.

[20] R. W. Imlay, "Lower Cretaceous and Jurassic Formations of Southern Arkansas and Their Oil and Gas Possibilities," *Arkansas Geol. Survey Inform. Cir. 12* (1940).
R. T. Hazzard, W. C. Spooner, and B. W. Blanpied, "Notes on the Stratigraphy of the Formations Which Underlie the Smackover Limestone in South Arkansas, Northeast Texas, and North Louisiana," *Shreveport Geol. Soc. Reference Report*, Vol. II (1945), pp. 483–503.

[21] Imlay, *op. cit.*, p. 54.

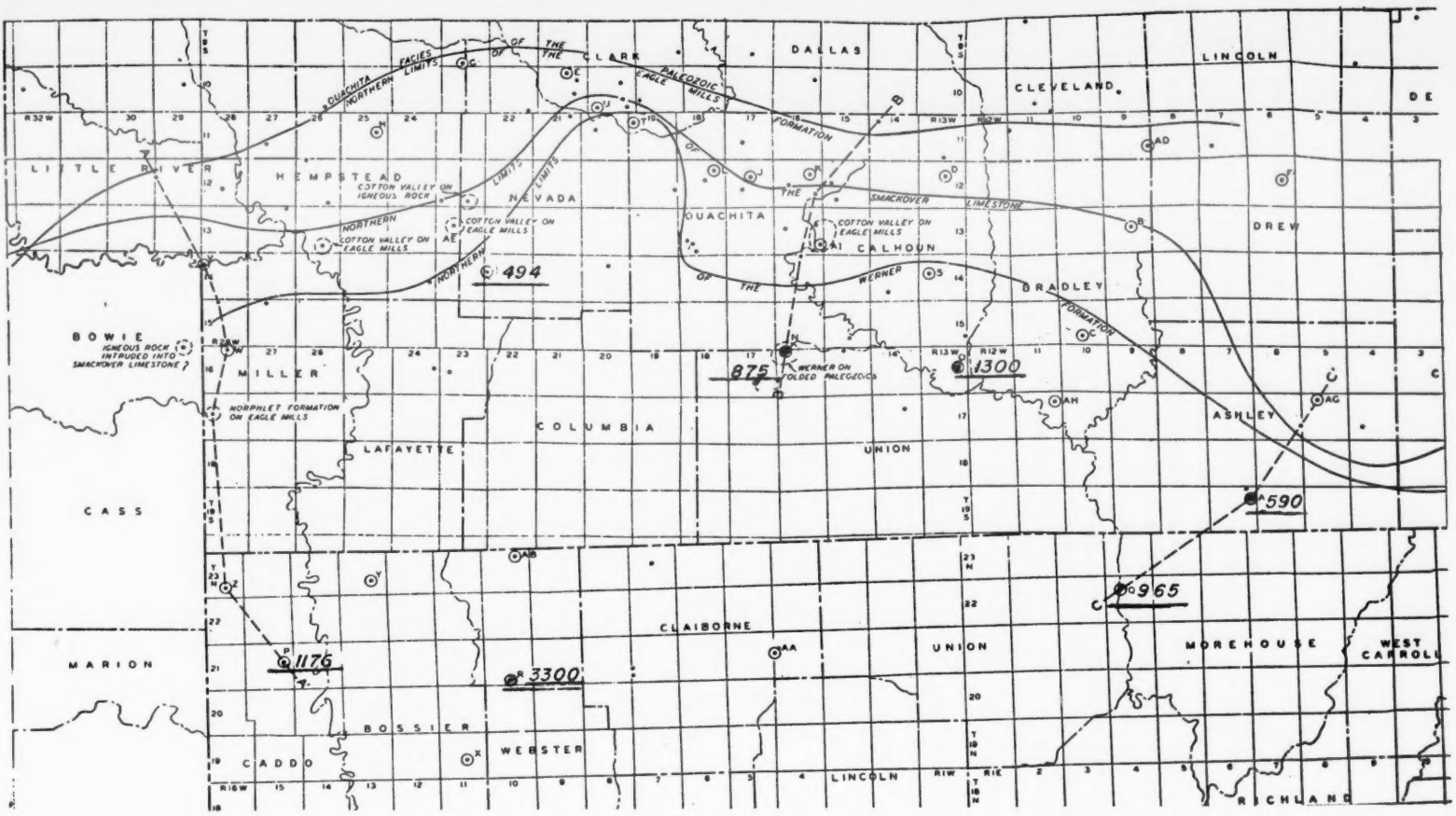



FIG. 1.—Map of South Arkansas and North Louisiana. Dots and circles indicate wells drilled through Smackover limestone or into older formations. Modified from map in *1945 Reference Report on Certain Oil and Gas Fields of North Louisiana, South Arkansas, Mississippi, and Alabama*, Vol. II, by Shreveport Geological Society; pp. 483–503; map following p. 503.

In Arkansas the sea of early Eagle Mills time advanced over a surface consisting mainly of Paleozoic rocks, and reworked a mantle of igneous, metamorphic, and sedimentary rocks into a basal gravel. Some red mud and red sand were deposited with the gravel. Red mud deposition was soon followed offshore by the accumulation of 50 to 100 feet of anhydrite and then by hundreds of feet of rock salt with minor amounts of anhydrite. In some places salt appears to have been the first sediment deposited. Still nearer shore only red beds were formed and these probably graded into terrestrial red beds. During Eagle

TABLE II

| *Former Interpretation of Stratigraphic Sequence [Imlay]* | | | *Authors' Interpretation of Stratigraphic Sequence [Hazzard et al.]* | |
|---|---|---|---|---|
| | *Unconformity* | | | |
| | Buckner formation | | Buckner formation | Jurassic |
| | Smackover limestone | | Smackover limestone | |
| Jurassic | Eagle Mills formation | Norphlet tongue | Norphlet formation<br>Red Beds with or without gravel | |
| | | | *Unconformity* | |
| | | Salt or Red Bed clastics | Louann salt | Permian |
| | | | Werner formation<br>Anhydrite member and Red Bed and Gravel member | |
| | | Louann tongue | | |
| | | | *Unconformity* | |
| Late Paleozoic | Morehouse formation | | Morehouse formation | |
| | | | Eagle Mills formation | |

Mills time the Gulf was surrounded by arid land masses and probably had small connections with the major oceans."

The shifting coast line of the Gulf thus described may have retreated southward to the margin of the coastal shelf, two or three hundred miles. There is no information available south of northern Louisiana, but if Hazzard, Spooner, and Blanpied are correct in their inferences, the conditions for sedimentary salt deposition extended to the region of the salt domes of the Gulf Coast. They say:[22]

Interpretation of the well data indicates that the Louann salt is a laterally continuous salt body which underlies parts of Texas, Arkansas, Mississippi, and Alabama, and probably all of Louisiana. The term "Louann salt basin" is used as a synonym for the Gulf

[22] Hazzard, Spooner, and Blanpied, *op. cit.*, p. 488.

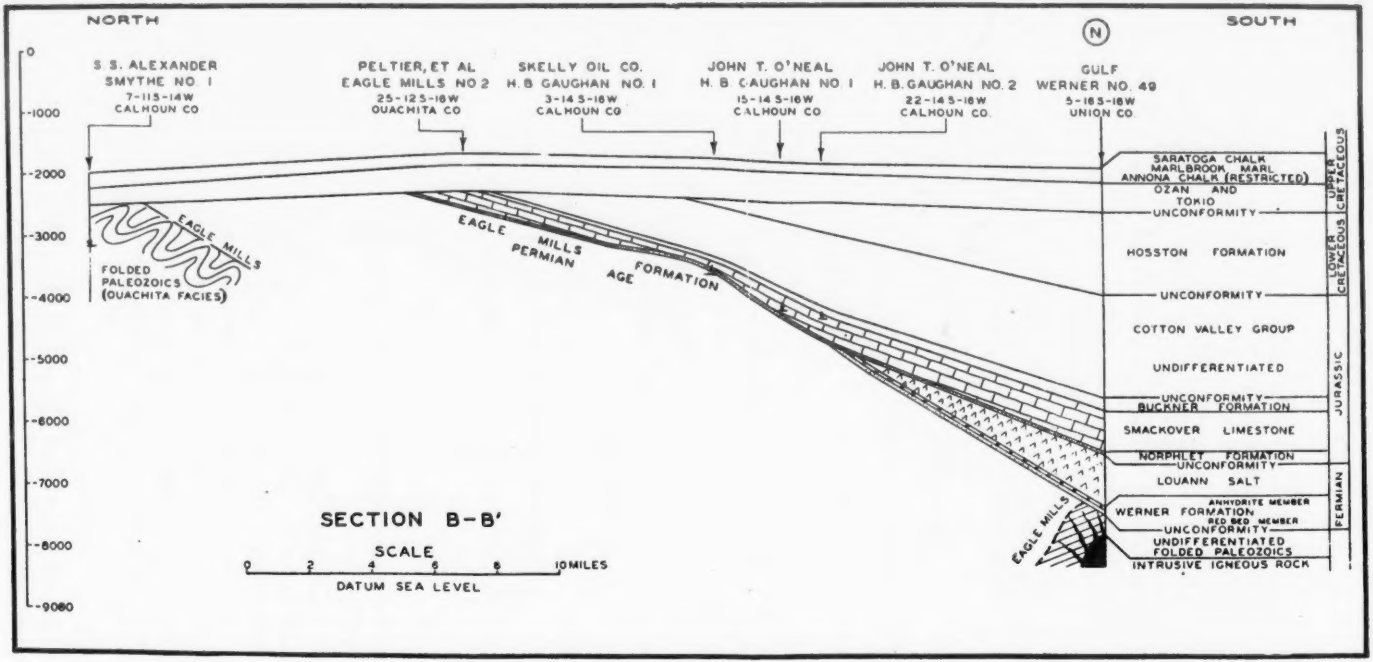



FIG. 2.—Section *BB'* (location on Fig. 1). From *1945 Reference Report on Certain Oil and Gas Fields of North Louisiana, South Arkansas, Mississippi, and Alabama*, Vol. II, by Shreveport Geological Society; pp. 483–503; section following p. 503.

coast salt dome basin. The maximum thickness of the Louann salt in Arkansas is 1,300 feet, recorded in a well in Calhoun County (O). The 3,300 feet of salt encountered in a well drilled in the Cotton Valley field in Louisiana (R) may be interpreted as an abnormal Louann salt thickness due to flowage. In so far as well records may be interpreted, the Louann salt is free of clastics. The maximum thickness of the Louann salt in the Louann salt basin is not known.

The reference letters (O) and (R) in the foregoing quotation refer to wells indicated on the map, Figure 1, and attention may here be directed to the five other wells in which the total thickness of the salt has been drilled, as indicated by the figures noted by each one of them and enumerated in Table III.

The 1945 Reference Report contains a wealth of detailed information regarding the various formations penetrated by the drill and their thicknesses and relations. Their inferred sequence and attitude are indicated in a section, *BB*, which is reproduced in Figure 2.

Imlay's description of the Buckner (late Jurassic) formation and of the Coastal Plain environment which it demonstrates runs as follows:[23]

> The Buckner formation is clearly a regressive deposit as shown by the transition from dolomitic beds at its base, to anhydrite in its middle, and to red beds at its top. The lowest dolomite beds overlying the Smackover limestone were probably formed in nearly normal marine water. The anhydrite and associated dolomite formed in highly saline waters. The highest red beds were probably formed in fresh or brackish waters as indicated by the presence of the normally fresh-water crustacean, *Estheria*. The regressive character of the Buckner formation is due to infilling from the land rather than to withdrawal of the sea, as the formation thickens southward, thereby showing that the ocean bottom continued to subside. Stratigraphic and paleogeographic relationships show that the waters in which the Buckner formation was deposited were connected southward with normal marine waters. Deposition in a marginal lagoon, rather than in a marine salina, or relic sea, is indicated by the large extent of the Buckner formation and the long but rather narrow transitional zone separating it from equivalent, normal marine dark shales toward the south. The barrier separating the lagoon from the open sea might have been built (1) by waves, (2) by reef-forming organisms, (3) by reef growths on a submarine swell, or (4) it might have been a submarine swell.

These conditions of geography and climate are what we would expect from the study of the climate of Permian time, and they would have favored evaporation from an enclosed lagoon such as Imlay suggests. However, the Buckner formation is separated from the Louann salt by the thick marine Smackover limestone, which means that the sea invaded the Coastal Plain before the retreat of the Buckner epoch. Consequently if the Louann salt was deposited under similar conditions the Smackover submergence must have been preceded by an emergence under arid climatic conditions and the retreat must have been co-extensive with the area of the Louann salt. It is supposed by Hazzard and his colleagues that the salt was a continuous bed, but the evidence is sparse and the alternative that there were separate local seas or lagoons appears at least equally reasonable.

We may imagine a sequence of coastal lagoons developing as the sea retreated

[23] Imlay, *op. cit.*, p. 24.

or advanced or we may suggest the alternative of inland basins such as that of the Caspian. Whatever these basins may have been, the geographic and climatic conditions appear to have favored sedimentary deposition of salt, normally including potash salts, by evaporation during late Paleozoic and earlier Mesozoic time.

*Cretaceous to Present.*—The conditions of aridity which had prevailed changed in the Cretaceous period to the humid climates which have characterized the Gulf region down to the present. The floras of the Cretaceous and subsequent ages are sufficient evidence of that change, which might, however, be inferred from the removal of the mountain barrier behind which the desert conditions developed, and from the general amelioration of climates the world over during the Cretaceous.

It follows that the climatic conditions since Mesozoic time have been such that rainfall has exceeded evaporation in the Gulf region and the deposition of salt by evaporation from any enclosed basin has not been possible.

## STRUCTURAL FEATURES

The subsidence of the northern Gulf since Permian time has resulted in the accumulation of a mass of sediments, probably more than 20,000 feet thick, under the present Coastal Plain. The strata lie on a very gentle dip, descending into the depths of the Gulf, and are generally regarded as a simple monocline. Although the total time lapse since the earliest deposits were laid down in Permian time is more than a hundred million years, the beds as a whole appear to be undisturbed. No "tectonic" (mountain) folding has been detected. Neither the Ouachita nor the Appalachian deformation is represented in the pile of sediments laid down in the Gulf.

In a general study of the structure it is desirable to distinguish certain major features, namely, the Gulf itself and diverse elements of its environment. We have expressed the view that the depression which the waters of the Gulf occupy was a part of the Atlantic basin prior to the development of the Peninsula of Florida. In terms of crustal structure the depression is a negative element. Florida, the Mississippi Valley region, and eastern Texas are, by contrast, positive elements of widely different ages and developments, but their characteristic tendency has been to stand high. The age of the granite of the Llano uplift is approximately eleven hundred million years. That of the continental interior is presumably even greater, whereas that of the Florida Peninsula may be only two or three hundred million, if it be assigned to the late Paleozoic granitic intrusions.

The movements of these crustal elements has been chiefly vertical, simply epeirogenic, in contradistinction to tectonic. The negative element of the Gulf basin may have subsided; at any rate the positive elements have certainly oscillated in position with reference to sea-level, as indicated by the advances and retreats of the shore line. On the whole, however, on the continental shelf the uplifts have exceeded the subsidences, and there has been a differential displacement between the rising continental elements and the stationary or subsiding area.

These movements have resulted in normal faulting in the slope between the areas of uplift and depression. Thus the Balcones fault system skirts the Llano uplift and extends northeast into the Mississippi embayment. Parallel systems of similar normal faults are known within the outer arc. The Sabine uplift appears to be similar in character to the Llano, a local development in a general continental mass. Positive and negative movements have presumably extended to the margin of the continental shelf in some instances, and the shore line has fluctuated north and south.

Minor structures have developed locally within the mass of sediments as they have accumulated on the submarine slope. They may be attributed to gravity, to creeping and sliding. Having been deposited under water the sediments contain water, which envelopes every particle and acts as a lubricant. It is squeezed out of the coarser beds by compaction, but adheres to grains in fine silts and they remain slippery. It follows that there is a tendency on the part of the overlying mass to creep down the slope, and to develop gentle undulations and even anticlines across the dip.

Creeping requires sliding and slides, of the nature of landslides, are liable to occur where the creep is marked. They are local structures which, like those on the land, have a back face and a toe in front, and the latter if sharply pushed up is commonly faulted. Submarine slides of that character are not infrequent. Some of them produce effects which are recognized as tidal waves or earthquake waves, the wave being due to the mass of water pushed away by the sliding mass of sediment. We may reasonably suppose that slides of that character have occurred in the Gulf sediments and that the beds are, in effect, faulted by that action. The movement of artesian waters would be materially influenced by such structures. Cutting across the beds, they would intercept the artesian flow, but the temporarily open fissure at the back of the slide would make easy the ascent of deeper waters under hydrostatic head. The auxiliary agency of an earthquake may not have been needed to produce slides in such a mass as has accumulated in the Gulf, but it is a very effective agency, and the Gulf region is now, and probably has always since the beginning of subsidence been, a more or less seismic area.

Attention may be directed to the sketch map of the major structural features of the western Gulf Coastal Plain by Imlay.[24] In southern Arkansas and northeastern Texas, the strata dip into the basin and exhibit a line of faults, in continuation of the Mexia faults and presumably due to the differential uplift between the rising continent and the sinking Gulf. They may also have occasioned slides. The slipping would be checked by the Sabine uplift, which may be explained as due to the rise of a positive element, like the Llano uplift. East of the Sabine uplift, there are several structures which may be due to differential movements of the buried basement or to gravitative adjustments within the Permian-to-Quaternary sediments.

[24] *Ibid.*, map following p. viii.

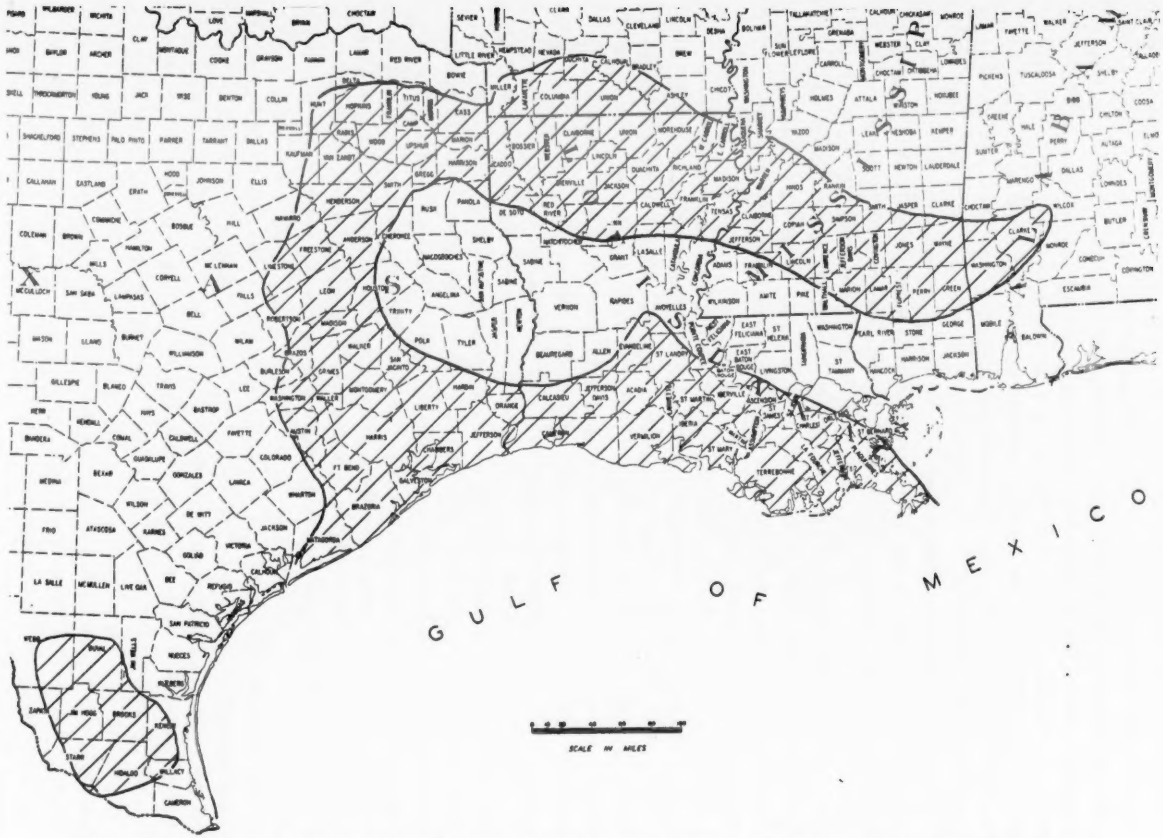



FIG. 3.—Map of parts of western Gulf Coast states of Texas, Arkansas, Louisiana, Mississippi, and Alabama, showing area thought to be underlain by continuous salt beds. By L. L. Nettleton.

Imlay[24a] thus described this structure:

A flexure, or steepening in slope, of the basement rocks in southern Arkansas and northeastern Louisiana, apparently paralleling the southern margin of the Ouachita Mountain folds. The position of this flexure is indicated by

(a) a pronounced erosional hiatus at the top of the Lower Cretaceous,
(b) thinning of Upper Cretaceous sediments,
(c) marked thinning of Lower Cretaceous sediments toward the north and east in contrast to great thickening toward the south and southwest, and
(d) lithologic changes from normal marine toward the south to marginal and littoral deposits toward the north and east.

The flexure formed the landward limit of the Eagle Mills salt, of the lower member of the Smackover limestone, and of the Buckner anhydrite.

Imlay's map is avowedly a sketch, the details of which are merely suggestive. But the fact of disturbance in that area is recognized by Hazzard and his associates.

Table III, showing total bored thicknesses of the Louann salt, is taken from the report of Hazzard and his colleagues. It shows the great variations in thickness of the salt and the irregularity of their distribution may be noted by reference to the map, Figure 1.

TABLE III

WELLS PENETRATING ENTIRE THICKNESS OF LOUANN SALT*

| *Location* | *Name* | *Map Designation* | *Thickness Louann Salt (Feet)* | *Thickness Werner Anhydrite (Feet)* | *Salt/Anhydrite Ratio* |
|---|---|---|---|---|---|
| Ashley Co., Arkansas | Union Producing Co., Crossett E-1 | A | 590 | 50 Approx. | 11.8/1 Approx. |
| Calhoun Co., Arkansas | Placid Oil Co., Freeman-Smith 3 | O | 1,300 | 90 + | 14.4/1 Approx. |
| Nevada Co., Arkansas | Placid Oil Co., Bodcaw Oil Co. 1 | I | 494 | 72 | 6.8/1 |
| Union Co., Arkansas | Gulf Refining Co., Werner Saw Mill Co. 49 | N | 857 | 57 | 15.0/1 |
| Caddo Par., Louisiana | Stanolind Oil & Gas Co., Dillon Heirs 131 | P† | 1,176 | 70 Est.‡ | 16.8/1 Est. |
| Morehouse Par., Louisiana | Union Producing Co., Tensas Delta A-1 | Q | 965 | 110 | 8/8/1 |
| Webster Par., Louisiana | Cotton Valley Oper. Comm., O.S. Banks 2 | R | 3,300 Plus | Not Reached | — |
| Limestone Co., Texas | Stanolind Oil & Gas Co., Norris 1 | | 790 | 60 | 13.2/1 |

* One exception: well R.
† Includes Werner Red Bed member.
‡ Drilling-time breaks at depths of 11,335 and 11,405 are interpreted to indicate presence of anhydrite between the salt and igneous rock.

These facts appeared to the writer to be inconsistent with the assumption that they represented the original unmodified condition of a sedimentary deposit

[24a] *Ibid.*, pp. 52–53.

and, on plotting the wells on Imlay's outline map of the structural features,[24b] he found that many of the wells lie in the general zone of the Monroe uplift. Structural disturbance and thickening of the salt, as in domes, might be the explanation of the irregularities.

In response to request for further information Hazzard has courteously and explicitly replied as follows:[25]

> The Cotton Valley structure is a very pronounced feature in the Jurassic beds. The one deep well penetrated 3,300 feet of salt before the hole was lost due to mechanical trouble.
>
> Nearby is the Homer structure, domal in shape, and much faulted. Two wells on the Homer structure have encountered salt below the Smackover limestone around depths of 6,000 feet. A flank well located several miles south of the center of the Homer structure was drilled to depth of 10,760 feet, penetrating approximately 1,100 feet of the upper part part of the Cotton Valley (Jurassic). Steep dips (approximately 45°) were observed in cores from near the total depth. Top of the salt in this well, using intervals known from other deep wells, is estimated at depth of 13,000 feet.
>
> Cores of the Smackover limestone and salt from the two Homer field wells showed dips up to 60°. An assumption may be made that the Homer structure defines a localized area under which an upward movement of the Louann salt took place of the order of 7,000 feet. This concept demands local tectonic thickening of the salt body of the order of 5/1.
>
> Detailed seismograph surveys of several of the elongate structural features of South Arkansas, such as Magnolia, Schuler, and Dorcheat-Macedonia, indicate that locally the Louann salt is much thicker under the structure than in areas adjacent to the structure. In these surveys, the top of the Smackover limestone is one reflecting horizon, the top of the Werner anhydrite the other. The regional Werner anhydrite structure of South Arkansas, based on seismograph work, is monoclinal, with southward dips of the order of 200 feet/mile or slightly steeper. Superposed on this regional picture, are all the structural features above mentioned. The Louann salt intervenes between the Smackover limestone and the Werner anhydrite; it is a justified conclusion that salt flowage has contributed to the deformation of the Smackover limestone since the Werner anhydrite shows nothing but regional southward dip.
>
> Seismograph surveys in South Arkansas have been of high order of accuracy and the geophysicists who have conducted these surveys have contributed much to the proper interpretation of the geology.
>
> Dips in the salt cores from the wells at Homer were determined on the basis of thin anhydrite stringers within the salt. One interpretation of these core observations is that the anhydrite and salt relationship represent an original depositional relationship.

The descriptions of "domal structures," dips in the salt and limestone up to 60°, the "upward movement of the salt" in the Homer field, and the thickening of the salt in other fields, may all be interpreted as being due to flowage of the salt into anticlinal structures or fault zones in the competent Smackover limestone.

The preceding consideration of the origin of the Louann salt relates to occurrences in Arkansas and northern Louisiana. Continuity of the salt with the Gulf salt-dome area is not yet demonstrated by any available evidence. The somewhat irregular occurrences of salt in the latter region may indicate a grouping over

[24b] Imlay, *op. cit.*, map following p. viii.

[25] R. T. Hazzard, personal communication.

districts that were the sites of individual inland seas in Permian time. Gravimetric surveys, the results of which are communicated by L. L. Nettleton,[26] suggest notable variations in thickness of the underlying salt, in some places more, in other places less than the 1,000 feet postulated by the general theory.

Hazzard and his colleagues[27] consider the deposition of the Louann salt as follows:

> The duration of the processes of evaporation and precipitation and the configuration of the basin are the principal factors which eventually determine the thickness of halite encountered in an evaporite sequence. . . . The areal extent and depth of the Louann basin probably were many times greater than the extents and depths of modern marginal pans and desert playas. In order to have some comparative figures of the thicknesses of halite to be formed under assumed conditions, two hypothetical cases have been set up.
>
> (a) A basin 3,100 feet deep, with a density stratification of the Dead Sea. . . . Brines rise from evaporation of sea water in an adjacent basin. Connection terminated at beginning of cycle. Bottom salinity 335 grams per liter; surface salinity 245 grams per liter; 91% of sodium chloride precipitated on reaching bittern stage; thickness of layer of compacted sodium chloride on evaporation approximately 300 feet.
>
> (b) A basin 9,000 feet deep; brines to rise from evaporation of sea water in an adjacent basin. Connection terminated at beginning of cycle. Bottom salinity 335 grams per liter. Surface salinity 326 grams per liter; 91% of sodium chloride precipitated on reaching bittern stage. Thickness of layer of compacted sodium chloride on evaporation approximately 1,000 feet.

The assumption of a basin 3,000 or 9,000 feet deep, behind a barrier of about the same height is required only if it shall have preceded and been completed before the excessive evaporation began. If we assume that the basin deepened and the barrier grew as evaporation progressed, the subsidence required to receive 1,000 feet of salt need be little more than 1,000 feet. Of course no other sediments, such as delta muds, may enter.

A general subsidence of 1,000 feet, indeed a general deepening of the Gulf by many times that amount, is proved by the thickness of the strata that fill it. But the growth of a convenient and adequate barrier remains a speculation. Imlay suggests a possible swell or a coral reef. Of these possibilities the latter appears the more probable and finds support in the example of the El Capitan reef of West Texas.

In view of the arid climate of the Permian, the assumption of inland basins may be reasonable. When filled and buried as they must have been by subsequent sediments, they could be detected only by geophysical exploration. Nettleton has courteously replied to a request for information as to the facts relating to the distribution and thicknesses of salt indicated by gravity surveys as follows.[28]

> On the attached outline map you will find two separate shaded areas. These represent areas where salt is presumed to exist because there are salt domes present, wells have drilled into the salt, or there are known geologic structures of dome-like form correspond-

[26] L. L. Nettleton, Gravity Meter Exploration Company, Houston, Texas.

[27] Hazzard, Spooner, and Blanpied, *op. cit.*, p. 500.

[28] Letter of November 1, 1947.

ing with gravity minima and which therefore are strongly indicative of underlying salt. While the areas have been extended in some cases by as much as a county or two between points of definite salt indication they are in general rather closely limited at the edges of the salt indications. They are drawn as minimal boundaries of the probably continuous broad salt basins.

The salt areas on Nettleton's map (Fig. 3) aggregate about 84,500 square miles, about 0.48 of the area of the Caspian Sea.

Nettleton explains further:

> The salt within these areas may vary widely in thickness. The estimate of at least 1,000 feet in the vicinity of Houston given you in a previous letter was based on a rather unusually close group of very large domes (as indicated by large gravity anomalies) in that particular area. There may be one or two other areas where a similar group could be found. Taken as a whole over the entire salt dome area the calculated figure for the minimum thickness of salt based on the salt volume derived from the gravity anomalies would be materially less but still probably would be some hundreds of feet.

These well supported observations leave no room to doubt the presence of salt formations equivalent in total masses in certain areas to a bed 1,000 feet thick. They do not, however, prove that there is a uniform bed of any particular thickness: the masses may be of any form, ranging from thin intrusive sheets of salt to domes of whatever height and to plugs; and the salt may be of sedimentary and artesian origin in indeterminate proportions. Deposition of the sedimentary salt from marine waters seems doubtful on account of the nature of the barrier which must be assumed to have been maintained for a considerable period of time. Deposition in inland seas seems reasonably probable and consistent with the geographic and climatic conditions of the region in Permian time. And contributions of salt from such deposits to artesian waters would inevitably follow the laws of solution.

In connection with the deposition of sedimentary salt there is a question to which so far as the writer knows no satisfactory answer has been offered: How is it possible for salt to be precipitated from muddy waters without admixture or interbedding with clastic sediments?

If one assumes a marine lagoon, however wide, within the geographic limits of the Gulf, one is confronted with the fact that even the broad Gulf itself is floored with sediment and strata are piled to great thickness. If one assumes an inland sea, there must have been tributaries and tributaries bringing in sediment. Dust storms would contribute. The environment in which salt could settle out as a sediment, free from sand or clay, must be rare indeed if settling out by gravity be the process of deposition.

The masses of salt which occur in the salt domes are remarkably free from sediment and in that respect they differ significantly from beds of salt deposited in evaporating seas. One may inquire why. How has the salt been separated from the sediment?

In certain other respects the salt in salt domes differs from that which would be deposited by evaporation of either surface waters or sea water. It contains anhydrite but is not associated with potash salts.

In normal precipitation from an evaporating water body, anhydrite, $CaSO_4$, crystallizes out before halite, NaCl, and occurs as a distinct layer underlying a salt bed, for example, the Werner anhydrite under the Louann salt (Table II).

In salt-dome salt anhydrite occurs as an impurity, as individual euhedral crystals, and as small bunches or layers. The euhedral crystals are very small but are so numerous that they occur very commonly in cores obtained in drilling wells.[29] They resemble phenocrysts in slowly cooled magma and may be explained as such, the assumption being that the brine contained a small trace of anhydrite in solution with the salt and it crystallized out before the salt did as the solution cooled. The bunches and layers may be interpreted as residual sediments freed by solution of the salt and caught in cavities within the mass.

The absence of potash salts may be explained by the fact that they are more soluble than halite and did not crystallize out when the salt was forced to by the cooling of the solution. In the concept here presented it is thought that a complex solution was rising to cooler horizons. It gradually cooled and lost each constituent as it reached the specific coolness for crystallization of either mineral; anhydrite first, halite next, but not for polyhalite (less soluble).

The growing salt dome may be compared with a tree in which the sap is rising and carrying up the elements of which it is built. The sap rises in the sapwood, an external layer, and promotes growth. In the confinement of the rock that surrounds the intrusive salt mass the growing column would develop internal pressure, would shear intimately, and would yield by displacements on the short, curved shears. Where solutions were retained they would be forced from fissure to fissure, from space to space, and would continue to deposit and to dissolve alternately as they were squeezed up.

This concept of persistent flow suggests a possible explanation of the anhydrite cap, as described by M. I. Goldman, Levi S. Brown, and A. H. Marx.[30]

In the upper part of the rising column the salt mass would be more open than below and internal waters would flow more freely. They would be diluted by meteoric waters and would dissolve salt and free anhydrite, which would accumulate as a sediment. This hypothesis of origin of the cap rock by solution and sedimentation is not new. It is considered by the authors named. But it is consistent with the concept of artesian origin of the salt domes. The brecciation and shearing of the cap rock would follow as a result of its position at the spear-head of the rising salt column.

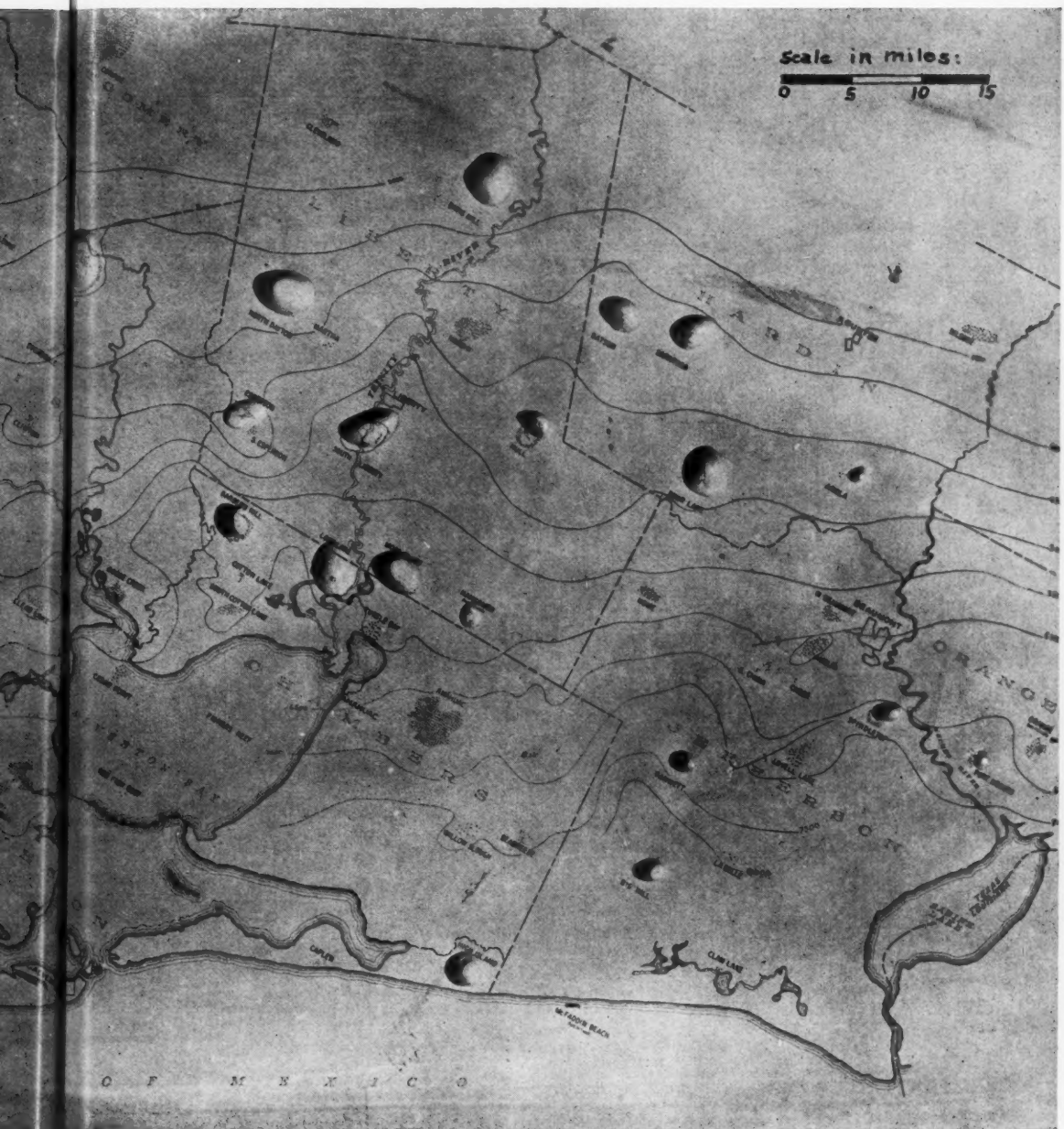
## DEVELOPMENT OF SALT DOMES

*Dome structures.*—The term salt dome, as used throughout these various discussions, refers to a unit which consists of two related parts, very much as a nut

[29] C. L. Moody, personal communication.

[30] M. I. Goldman, "Petrography of Salt Dome Cap Rock," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9 (1925), pp. 42–78.
Levi S. Brown, "Cap-Rock Petrography," *ibid.*, Vol. 15 (1931), pp. 509–29.
A. H. Marx, "Hoskins Mound Salt Dome, Brazoria County, Texas," *ibid.*, Vol. 20 (1936), pp. 155–78.

FIG. 4.—Photograph of model of subsurface configuration of salt in domes of southwest Texas Gulf Coas




xas Gulf Coast. Contours on top of middle Oligocene *Heterostigina* zone. Contour interval, 500 feet.

consists of a shell and a kernel. The shell of a salt dome is the domed and faulted envelope of strata. The kernel is the lens or column of salt. They differ not only in materials, sandstone contrasting with salt, but also very significantly in texture and structure; the one being granular, the other crystalline, the strata being faulted, the salt being intensely folded. It is helpful to describe them separately.

For the structure of the envelope, of the surrounding masses of sandstone and shale, we are indebted to C. B. Roach and W. E. Wallace, Jr. Wallace[31] states:

> All of the structures (of deep-seated domes) studied contain one or more normal faults. In most of these structures, the faults are arranged so that they form a graben which is located in the approximate center of a gently domed region. The typical graben is not simple. It is complex, with one or more extra, flanking fault blocks. The location of the graben directly above the top of the salt plug on the Lake Mongoulois deep-seated salt dome suggests that deep domes have a central vertical axis around which the various structural elements are arranged in a more or less symmetrical pattern. This axis passes vertically through the salt column, through the center of the graben, and through the center of thinning of the sediments above.
>
> The principal structural elements of grabens are determined by major normal faults with throws of several hundred feet.

This general statement, which is based on the examination of a thousand electric logs, may be taken as the basis for an interpretation of the action which has produced the major structures. Wallace followed common practice in attributing the normal faulting to tension. Under some conditions, as in the elongation of a diagonal of a rhomb that is pressed into a diamond shape, that explanation is correct; but normal faulting also results from the action of a vertical lifting force, just as reverse faulting develops under horizontal compression. The mechanical consequences are similar, but at right angles with one another.[32] Wallace[33] describes the development of deep-seated domes as the result of the vertical, upward thrust of the salt core and he ascribes the lifting force to the pressure of the overlying sediment upon the salt, in accord with the postulates of the "accepted" theory.

We may agree upon the action of a lifting force and may also concede that that force is in part due to the weight of sediments, which presumably squeezes the salt up as in an hydraulic press once an outlet is provided by a slide or other accident. This is as Nettleton has shown, except that the envelope has yielded by faulting like a solid.

After describing the successive development of major and minor normal faults, Wallace continues:[34]

[31] W. E. Wallace, Jr., "Structure of South Louisiana Deep-Seated Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1934), p. 1251.

[32] Bailey Willis, "Normal Fault Structures and Others," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30 (1946), pp. 1875–87.

[33] Wallace, *op. cit.*, pp. 1305–06; Fig. 37.

[34] Wallace, *op. cit.*, p. 1307.

If salt cores could rise under conditions of perfect confinement on all sides, they would cause a conical distribution of maximum stress in the rocks above them. Rupture under such conditions would produce a conical fault with a circular surface trace. The apical angle of the inverted cone would be about 90° and the dip of the fracture about 45°. Such a hypothetical cone is not actually created because the strength of the materials is not sufficient to bear the burden of the cone and because the salt does not rise under conditions of complete horizontal confinement.

In his summary Wallace states:[35]

Deep-seated domes are developed by the upward movement of a salt plug which first causes the deeply buried layers to be gently domed. Continued salt movement causes rupture in the form of a major, normal fault extending diagonally upward through the dome from the head of the salt plug.

This concept of the development of a dome into an intrusive plug is consistent with the assumption that attributes the lifting pressure to the load, and it may also be deduced logically from the growth of the crystalline mass of salt from artesian brines. Since in the Artesian theory the force of crystallization is substituted for gravity as the principal cause of uplift, it will be discussed in that connection.

The structure of the salt core, the active, vital part of a dome or plug, may be seen in several mines along the Gulf Coast. The writer observed it in the Morton mine of Grand Saline, Texas, at a depth of 700 feet below the surface and about 15,000 feet above the base of the salt plug, as determined by gravity measurements. The diameter of the plug is about a mile. In a large chamber, 120×90×60 feet, the vertical walls of pure salt exhibit intense shearing. Each shear is a displacement in an upward direction on a curved surface of limited extent. There is no regularity of horizontal arrangement or strike. The shears are plainly effects of converging pressure directed inward toward the heart of the column, and the movement has been upward toward the least resistance.

The writer did not notice the section of this structure which was exposed in the roof, that is, the section which may be seen by an observer lying on his back. That has, however, been done by Robert Balk in five salt mines and he describes it as a group of irregular folds:[36]

*Megascopic structure.*—The salt in all five mines shows a layered structure of white and gray salt. White salt is almost pure halite; gray salt contains a small proportion of anhydrite and, rarely, a few additional compounds. Salt layers vary in thickness from a fraction of an inch to several feet; white salt seems far to exceed the amount of gray salt. Layer boundaries, sharp from the distance, are elusive in hand specimens, and salt crystals, about ¼ cubic inch in size, may grow across layer boundaries. Most grains seem to be equant, and the texture of the salt is compact, but in a few places distorted halite crystals were seen in crude alignment, resembling the structure of coarse-grained gneisses.

*Folds.*—On vertical walls of the mines, salt layers stand in nearly vertical position.

[35] *Ibid.*, pp. 1311–12.

[36] Robert Balk, "Salt-Dome Structure (Preliminary Notice)," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 31, No. 7 (July, 1947), pp. 1295–99.

Dip angles as low as 45° were noted in places, but seem to be the exception rather than the rule. In sharp contrast with this rather monotonous succession of steep salt layers on the walls is the salt structure in the ceilings. Here a remarkable array of folds is exposed in cross section. Their axes are nearly vertical so that the observer looks nearly parallel with them, and the horizontal ceilings are cross sections of the folds. Large folds must be traced through contiguous tunnels and rooms, but under favorable conditions they can be followed for hundreds of feet. Smaller folds are completely exposed within individual room ceilings (Fig. 1). There are open folds as well as isoclinal folds. Many limbs carry smaller secondary, and even ternary, folds, and tightly appressed shear folds are common among these. How far individual folds can be traced will depend on the orientation of the mine tunnels and also on the persistence of salt layers. As in folded marbles, dark salt layers tend to lens out, and may be lost even where ceiling exposures continue.

Looking up at places where several groups of limbs have been kneaded into each other, one can not fail being impressed by the immensity of deformation which the salt has fixed by its fold structure.

*Development according to sedimentary hypothesis.*—A salt dome presents a problem in mechanics involving the lifting of a weight of sediments in such manner that flat strata are locally arched or domed in the early stages and are intruded and faulted in later stages. The deformation requires a lifting force, which, according to the hypothesis of a sedimentary salt bed as the origin of the dome, is due to the weight of the strata on the salt. The bed of salt is thought to have been deposited by evaporation from ocean waters and is calculated to be perhaps 1,000 feet thick. It may be assumed to have the crystallinity of rock salt. The overlying strata are of sandstone, shale, and limestone, which are hard and more or less indurated, to judge by hand specimens or cores. The specific gravity of the salt is less than that of the strata. Under these conditions it is assumed that the weight of the strata squeezes the salt up into an incipient arch and develops that structure into a dome. The effect may be described as an intrusion of salt, produced, according to the hypothesis, by the greater wieght of the sediments, which the salt is unable to support.

The Committee[37] presents this concept in the following words:

> The salt flows primarily because of the instability resulting from a low density layer being under a high density one. . . . It is assumed that salt and sediments through long periods of geologic time flow in a manner similar to that expected of highly viscous fluids.

Nettleton[38] explains more fully:

> The following pages present the conception that the formation of salt domes is essentially the movement of very viscous fluids under gravitational forces. A simple mathematical formulation of the forces and movements and some simple experimental demonstrations are given. . . . The fluid conception has developed gradually with the writer in connection with interest in salt dome forms from an analysis of torsion-balance gravity surveys over domes in the Gulf coast, northeast Texas, and north Louisiana. The hypothesis

[37] See Introduction.

[38] L. L. Nettleton, "Fluid Mechanics of Salt Domes," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 18 (1934), pp. 1179.

of the formation of domes as a result of fluid movement under gravitational forces is the natural result of the indications that for all domes for which data are available to the writer: (1) the salt is lighter than the surrounding sediments, as shown by gravity surveys, and (2) the domes all have a circular, or at least a generally rounded form, suggesting that their form is controlled by yielding and flow of the surrounding material, and not primarily by fracturing.

Evidence on the first of these indications is fairly definite and quantitative; on the second (flow of salt and sediments) it is highly qualitative.

In the discussion of this process the terms "solid" and "viscous fluid" are used to describe the physical state of the salt and of the sediment also, and the usage of the terms fluid and solid is open to question. As a basis for this discussion, the writer offers the following definitions. *A solid is a substance which in response to an adequate stress may be deformed by fracture and shearing, the shearing developing in definite planes, oriented approximately at 45° to the principal stress. A fluid is a substance which adapts itself to its environment by shearing in any direction toward the least resistance, but not on definite planes.*

These definitions are obviously limited to the mechanical effect of shearing. Another definition of the solid state is commonly framed on the characteristic of elasticity, which is possessed by solids, but not by liquids; it unfortunately is not available in discussing the behavior of deeply buried sediments. The distinction based on the manner of shearing can, however, be observed and the foregoing definitions are designed to express it.

An intermediate plastic state, between solid and fluid, should be mentioned in this connection, namely, that of a substance which *shears* under the pressure of a dominant stress, yet will *flow* into an area of relief from confinement. The writer observed an instance of this nature in 1886, when experimenting in the folding of strata. His pressure-box had a plate-glass front, which suddenly cracked as the model was squeezed under the load of 1,000 pounds of shot. A soft, thick layer, which was shearing on sharply defined planes, like a solid, instantly spurted out through the cracks and stood out in thin projections, like paper, a quarter of an inch more or less. While intruding the cracks it behaved instantaneously like a viscous fluid; under persistent stresses it was sheared like a solid.

The question presented by the postulate offered by the Committee is: *Have the salt domes been pushed up by the weight of the sediments, acting as a load on the salt?*

Nettleton[39] has produced domes that resemble the forms of actual salt domes so far as they have been determined by the drill. In all the experiments both salt and sediments have been represented by viscous fluids. In the earlier trials crude oil was used to simulate salt and corn syrup for the sediments. In the most recent

[39] L. L. Nettleton, *op. cit.*, pp. 1175–1204.

———, "Recent Experimental and Geophysical Evidence of Mechanics of Salt-Dome Formation," *ibid.*, Vol. 27, No. 1 (January, 1943), p. 51.

———, "Geologic Models Made from Granular Materials," *Trans. Amer. Geophys. Union*, Vol. 23 (1947), pp. 451–65.

test the syrup stood for the salt and a heavy mud of finely ground barium sulphate ("baroid") was taken for the sediments. In all the experiments the lighter, more fluid under layer was forced up through an initial opening or weaker section of the upper, heavier one by the weight of the latter. The mechanical action resembles in principle that of a force pump, but one of special design, since the syrup rises through the baroid, which acts as a piston, pressing down by gravity.

The assumption that fluids may structurally represent salt and sediments is a necessary one in order that the stresses and resistances be brought within the range of laboratory equipment. The procedure is calculated according to the formula offered by M. K. Hubbert[40] for the reduction of natural conditions to those that are within reach of the experimenter. The question which is here raised in that connection is not whether the calculation has given a true result, but rather whether the salt and strata have actually behaved as viscous liquids.

The fact that salt may appear to have flowed under adequate pressure is recognized and may be explained by the relative ease of movement of the molecules past each other on cleavage planes.[41] Displacements may occur on any one of four directions, and the shearing is first opposed and then aided by the atomic forces in each molecular movement. The displacements combine to larger movements, and a mass of rock salt taken from such a body as Grand Saline exhibits curved shearing planes, or slickens, in all directions. An X-ray examination of a salt specimen taken from the Grand Saline mine at a depth of 700 feet shows that the atomic structure, the crystal lattice, has been restored in spite of the general shearing, because the movements have been on cleavage planes and the displacements have restored the atomic structure. The manner in which the crystalline structure of the salt is restored and evidence of gliding is thus obscured is explained by Eleanora Knopf:[42]

> In translation gliding the continuous differential slip takes place along crystallographic planes. In contrast to twin gliding the amount of differential displacement on each gliding plane is a whole number of interatomic distances. Thus the crystal remains optically unchanged by this process of pure translation.

In thus shearing on oriented crystal planes, salt differs from a viscous fluid, which may be described as a substance which will shear in every direction, indifferently.

In regard to sediments it is difficult, at least for the writer, to comprehend in what sense the term fluid may be used to describe the change of form, the fracturing, and faulting, involved in the growth of a dome. In response to an inquiry as to his usage, Nettleton has courteously replied as follows.[43]

[40] M. K. Hubbert, "Theory of Scale Models as Applied to Geologic Structures," *Bull. Geol. Soc. America*, Vol. 48 (1937), pp. 1459–1520.

[41] Bailey Willis, "Eruptivity and Mountain Building," *Bull. Geol. Soc. America*, Vol. 52 (1941), pp. 1666–71.

[42] Eleanora B. Knopf and E. Ingerson, *Structural Petrology*, Chap. 7, p. 91.

[43] L. L. Nettleton, letter of September 26, 1947.

The evidence that the sedimentary material surrounding salt domes behaves "as a highly viscous fluid" is indirect. I know of no samples or drill cores which demonstrate this behavior. Furthermore, the scale of the phenomena as I see it is such that it would not be evident in a drill core any more than one would expect to see in a sample cut from buried anticline, even though sharply folded, to contain direct evidence of the flowage which may accompany such folding. Furthermore, the above statement in quotes is undoubtedly over-simplified and if we knew the actual conditions we would probably find that the present configuration of the material surrounding the salt domes has been reached by movements involving flowage and fracture in a very complex mixture.

In this explanation, Nettleton again recognizes fracturing as a condition of movement in the development of domes, though he assigns it a minor role as compared with flowage. We are thus returned to the question, what is the evidence of flowage in the sandstones themselves? The descriptions given by Wallace[44] demonstrate very adequately that the major structures in the salt domes are fractures and faults, definitely similar to those which are found cutting through rigid rock masses, which are generally regarded as solid. Thus it would seem that the term "fluid "must be used to describe the internal structure of texture of the sediments in the salt domes, if at all.

The texture of the sandstones in question, when examined in cores from deep wells, failed to show any indication of the realignment of particles, such as might be produced by flow. Thin sections were examined under the microscope by Professor Charles Park, with the same result. In the foregoing quotation, Nettleton states that he does not know of any cores that would demonstrate flowage.

However, one other factor is introduced in the statement of the Committee by reference to the idea that the flow has been a very gradual movement "through geologic time." Nettleton calls attention to the warping of grave stones supported at the four corners by columns and cites the change of form as an example of flow. The case is one which has been explained as an effect of solution in rain water and recrystallization through evaporation. It appears that the calcite crystals go into solution where under strain and in recrystallizing assume an adjusted orientation that restores the crystal symmetry. This is a kind of molecular flow, but it is peculiar to crystals of calcite or salt or other crystalline minerals, and would not apply to the granular sediments involved in the salt domes.

It would seem from this examination of the evidence that the sediments involved in the doming have not flowed after the manner of viscous fluids; indeed it may be said they have behaved like solid rock.

The behavior of the sandstones as a solid does not, however, alter the action of the load upon the salt. Given a passage of escape for the latter and an adequate unit weight on the area around it, it follows according to the principles of the hydraulic press that the semi-fluid salt must yield. The vertical upthrust thus initiated will persist indefinitely and must be recognized as a persistent stress, which is one possible cause of the initial rise of domes and plugs. The mechanism

[44] Wallace, *op. cit.*

is the same as that which has been designed by Nettleton, except that he substituted a heavy fluid for the solid rock. The effect would be the same, whatever the nature of the load.

*Development according to Artesian hypothesis.*—It is assumed that the artesian basin of the Gulf has received saline contributions from percolating waters ever since Smackover time or before that epoch.

It is thought that the salinity of waters circulating in the sediments developed into brines by diffusion of the salt in adjustment to temperature, by gravity, and by solution of buried salt beds. If petroleum be present we may add the expansion of gas on release of pressure, the cooling due to expansion, and the evaporation of water into the moving, escaping gas.[45] Deeper solutions are thought to have become heavy brines in the course of time and to have relatively high temperatures. In view of the wide range in salinity of the percolating waters from Alabama to Texas and the irregular distribution of salt beds, it is improbable that uniformity can have been established in the underground currents.

The ideal circulation would been have through pervious beds and might be thought to have been confined to individual sandstones; but such formations are lenticular and overlapping, even if undisturbed, and that latter condition can hardly exist. As has been stated under the heading of Structure, pronounced normal faults are known to break the continuity of the strata. There is also good reason to assume the existence of flexures due to creep, and also submarine slides. The terraces and low anticlines thus formed should strike across the dips and, where fractured, may be expected to have facilitated the upward movement of solutions. Faults and slides, both, would be relatively quite local, though having a tendency to occur where the dip was slightly steeper and so to be ranged along the outer slope below the crest.

If a body of heavy, stagnant brine had accumulated in the bottom of the basin, it would move if disturbed by a slide or other accident. Rising to cooler levels it would become saturated in consequence simply of change of temperature and salt crystals would necessarily form. It has long been known that they do so with great force and Harris regarded that force as the one that had raised the salt domes and plugs. His views are confirmed by the better understanding we now have of the manner of formation of molecules, such as that of NaCl.

The crystal unit or molecule of common salt comprises 8 atoms, 4 of sodium and 4 of chlorine, located at the 8 corners of a cube and so arranged that they are bound together by attractions along the sides, but prevented from being drawn into the center by repulsions on the diagonals. The structure is well illustrated in the easily accessible book by Krauskopf.[46] When free the ionized atoms have respectively sodium 9 and chlorine 7 electrons. As 8 electrons form a more stable

[45] R. Van A. Mills and Roger C. Wells, "The Evaporation and Concentration of Waters Associated with Petroleum and Natural Gas," *U. S. Geol. Survey Bull. 693* (1919), pp. 1–2.

[46] K. Krauskopf, *Fundamentals of Physical Science*, pp. 312–13.

combination, each gains by the transfer of 1 electron from the sodium atom to the chlorine atom. This transfer is accomplished in their combination, which takes place violently and with great force.

The product of the combination is crystalline NaCl, the well known, chemically very stable substance, which in crystallizing from solution exerts a force that is greater than its crushing strength. That fact has been demonstrated by the experiments on the growth of crystals by Becker and Day of the Geophysical Laboratory in Washington, who in 1902–1903 experimented on this force and its limits.[47] They reached the conclusion that the molecular growth of a crystal in a supersaturated solution may exert a stress at least up to the crushing strength of the crystal, and they demonstrated this result in further experiments in 1916, in consequence of criticisms by the physicists Bruhns and Mecklenburg, who failed to observe crystal growth in repeating the experiments made by Becker and Day. The latter explain this failure as a condition imposed by slight differences of concentration of the solution. The detailed discussion is beyond the scope of this paper, but the relation of the potential concentration of the solute to the growth or static condition or solution of a crystal was clearly demonstrated by Becker and Day and is of significance in the problem of salt-dome development.

The process of crystallization from rising artesian brines may be analyzed somewhat as follows. A strong but not saturated brine rising in the artesian circulation from warmer to cooler horizons may reach a saturated condition in which the salt separates molecule by molecule from the water. The force with which a salt crystal forms is that of the electric charges of the atoms in transferring one electron from the sodium to the chlorine and establishing the balanced relations of the positive and negative elements in the cubical crystal lattice. This force has no direct relation to the crushing strength of the resulting crystal, except that it is greater, and, when the crystal grows in confinement, is powerful enough to crush crystalline salt. It is evident from the crushed and folded condition of the salt in salt domes that a force of this intensity has acted as the volume of the mass has increased.

It was shown by Becker and Day that crystal growth occurs on preferred surfaces where favored by a stronger solution or by freedom of access to the crystal. The strength of the solution at the point of growth may be influenced by the presence of another crystal less favorably situated, which may even be dissolved. This means transfer of the salt in the direction of flow. Freedom of access to the crystal surfaces means access of the solution to a crystal surface in contrast to an obstructed condition, such as when the crystal rests against a foreign substance. In their experiments, the latter condition was imposed by contact with a glass plate, while the more rapid growth occurred on the exposed sides of the

[47] G. F. Becker and Arthur L. Day, "The Linear Force of Growing Crystals," *Proc. Washington Acad. Sci.*, VII, Vol. 24, No. 4 (1905), p. 283.
———, "Note on Linear Force of Growing Crystals," *Jour. Geol.*, Vol. 24 (1916), pp. 313–33.

original crystal. In the case of an intruding layer of salt on a bedding plane, the preferred locus for crystallization from intruding brines would be on the under and upper surfaces, and the cover would be pushed up as the salt accumulated molecule by molecule. Growth would also occur around the margins where the brines spread laterally and the effect would be to produce a rounded lens, that is, an incipient salt dome.

Eventually the growing salt mass would distend the cover and produce joints into which the brine would penetrate. There would presumably be a network of fissures and intrusions, and growth in all directions, resulting in the rounded form. The intruding salt, growing in volume within confining walls, under intense compression, would itself be sheared and would be displaced on curved shearing planes. It would thus be traversed by irregular fissures in all directions. Brine would penetrate the mass and continue to flow up. Crystallization of salt on salt within the mass would constantly tend to close fissures and open new ones. Growth would continue more freely on the outside upward in the direction of least resistance. The top of the dome or plug would therefore be cupped. The upward thrust would cause the normal faulting of the envelope, already described.

We may suppose this process to be continued through one or more geologic periods, and to result in a broad dome or where it proceeds to the intrusive stage in a tall plug with cup-shaped top.

In a dome the salt would lie in layers where it crystallized from the infiltrating solution under the cover. Around a plug it would also be crystallized in layers, parallel with the vertical cylindrical surface, and would thus develop a structure consisting of innumerable envelopes. Each layer would be crystallized from a film of solution intruded by hydrostatic pressure and atomic attraction along the surfaces of the salt. Crystals would form forcibly and exert pressure upon the walls and upon the column of salt. The salt column would grow in diameter and height, growing most vigorously in its outer shells.

When checked against the internal structure of the salt core, as observed by Balk and the writer, this explanation appears to be consistent with the facts.

This process of growth appears competent to explain certain observed structures, namely, the folding observed by Balk in the ceilings of mine chambers in the salt and the "rim syncline."

Folds within the salt dome present vertical axes, as they would if caused by horizontal compression combined with least vertical resistance. The folds are very irregular, as seen in horizontal section, and thus demonstrate that the compression in that plane lacked orientation, that is, it was from any or all directions, inward along radii, with varying intensities. The folding is interpreted as due to radial growth of the salt column against the confining envelope.

The envelope has been displaced horizontally, as appears where the strata are folded outward from the salt column, and it has been pushed up on normal faults by the vertical intrusion, due to horizontal squeeze.

The rim syncline owes its development to a stress that had an outward and downward direction, so that the push was away from the salt and down. The radial outward component was due to up-growth and expansion of the salt column. The downward component was developed by the envelope, which was dragged up at the contact with the rising salt, so that it dipped away from the column all around. The stress transmitted to the envelope at the top of the salt was thus outward and downward. It held the surrounding strata down and so caused the syncline. The writer observed this relation of stress to synclines and anticlines in making experiments on folding in 1887.

## CONCLUSIONS

1. An arid climate similar to that of western Asia prevailed over the Gulf region and interior North America during Permian time and persisted into the Jurassic.

The shoreline of the Gulf fluctuated from a northern position across Arkansas possibly to the outer edge of the continental shelf, the major contrasts being recorded in retreating shorelines and extensive land areas in Permian and upper Jurassic (Buckner) periods and in the marine, Smackover invasion.

The foundations of the region were unstable and the general plus or minus warping of the surface varied locally in such a manner that basins developed. If marine waters had access to such a basin as through a coral reef, and evaporation equalled or exceeded inflow, a salt deposit of oceanic origin developed. If the basin was an inland depression like the Caspian, the salt was contributed by surface run-off.

2. Appropriate conditions for artesian circulation were intiated as the outcrop of any pervious bed rose above sea-level and the submarine extent of the pervious stratum became buried under in impervious layer. The earliest record of these conditions appears to be found in the terrestrial deposits that were spread over the Louann salt and were succeeded by the Smackover limestone. Percolating underground waters were relatively strongly saline during the persistence of desert conditions and became even more so in the deep circulation by dissolving the sedimentary salt. The conditions were favorable for the development of strong brines in the depths of the subsiding basin.

3. The structure of the Gulf sediments is not that of a simple monocline, except in general terms. Although there has not been any tectonic activity, there probably have been local epeirogenic uplifts, such as the Sabine, and local depressions of similar origin. Creeping of the mass of strata has probably affected various sections and slides have produced breaks and crumpling. Normal faults occur. Any of these structures may have checked or diverted, or concentrated artesian circulation in specific sections and have modified the local salt formations.

4. The salt that now occurs in salt domes and plugs has been crystallized from rising artesian brines which reached the point of saturation for NaCl and deposited crystalline salt wherever they penetrated, on bedding planes, on un-

conformities, or in openings caused by faulting, submarine slides, or other conditions.

Crystallizing salt exerted a force greater than the crushing strength of the salt itself and each molecule took up space accordingly.

Where the salt solution penetrated between flat-lying strata, doming resulted, as Harris said, or where a plug developed the accretion of salt would be on the outside and the growth would be by the addition of layers around the plug. The upward growth would be most vigorous in the outside layers and the upthrust of the whole plug would be due to the combination of the crystal pressure with that vertical force which results from the action of the load of overlying sediments upon the viscous fluid salt. What that load may have been at the time of growth of any dome or plug we can not estimate, for the level of saturation of the rising solution and consequently of the base of the formation is indeterminate. If the brine was relatively weak that level would have been nearer the surface; if the brine was stronger the base of the plug would be deeper.

The "rim syncline" and similar structures have been produced by stresses generated in the growth of the dome. The cap rock is presumably a sedimentary deposit on top of the dome, accumulated by solution of the NaCl and sheared and brecciated by the pressure of the rising mass.

5. The drill has discovered a body of facts that materially change our ideas of the environment of the Gulf in past ages. Considerable progress has been made. Yet in view of the scanty data available positive assumptions are dangerous. A complete hypothesis of the origin and formation of salt domes can be framed only upon adequate consideration of the geologic, physico-chemical, and atomic processes involved in their development since the Permian, during more than one hundred million years.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1265-1274, 3 FIGS.

# CORRELATION OF SENTINEL BUTTE SHALE IN WESTERN NORTH DAKOTA[1]

ROLAND W. BROWN[2]
Washington, D. C.

## ABSTRACT

New stratigraphic and paleontologic evidence indicates that the Sentinel Butte shale, lately considered by some geologists to be of Wasatch (Eocene) age, is, as originally described and assigned, a dark sequence of strata in the upper part of the Fort Union formation (Paleocene). A diagrammatic cross section illustrates the writer's correlation of formations and members in the Paleocene and Eocene series of eastern Wyoming, Montana, and the Dakotas.

## GEOLOGIC BACKGROUND

Sentinel Butte, 3,331 feet above sea-level, is a high mesa 2 miles south of the town of that name along U. S. Highway 10 and the Northern Pacific Railway in western North Dakota (Fig. 1). It is visible for many miles from all directions on the surrounding plain above which it projects about 500 feet. Approaching

FIG. 1.—Looking south toward Sentinel Butte, North Dakota. June 24, 1947.

this prominent landmark from Marmarth, 45 miles on the south, the observer may travel northward to the crossing of the Little Missouri River at Yule. In this stretch the oldest rock exposures seen along the river (see Sentinel Butte-Mar-

[1] Manuscript received, April 9, 1948. Published by permission of the director of the United States Geological Survey.

[2] Geologist, United States Geological Survey.

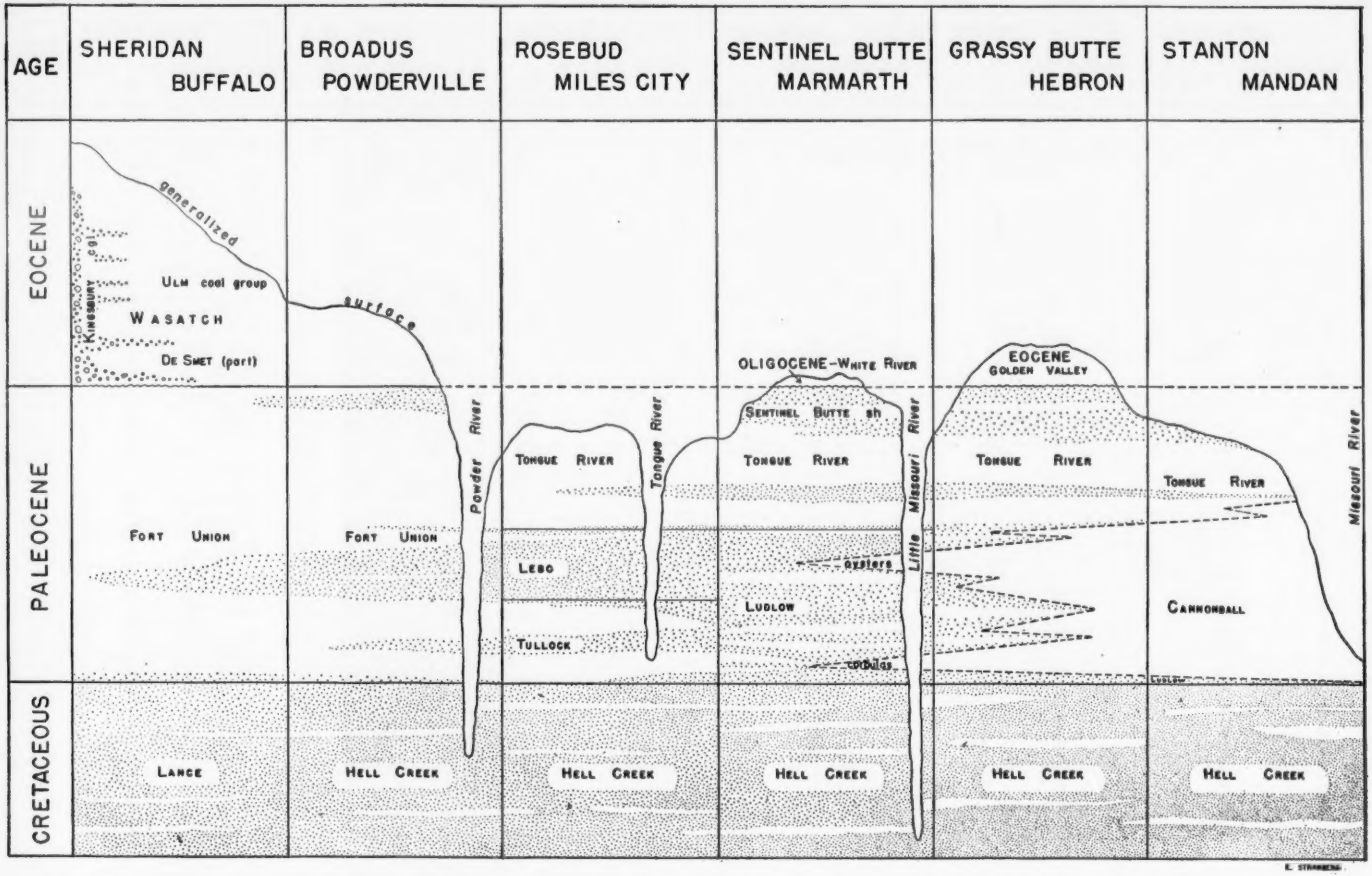



FIG. 2.—Composite cross section from Sheridan, Wyoming, to Mandan, North Dakota, showing correlation of Cretaceous and Tertiary formations as interpreted by the writer. The Broadus and Rosebud columns are interchanged deliberately to show closest relations to adjacent columns. Stippling in Cretaceous and Paleocene nonmarine parts does not indicate sandstone but dark zones of strata of all kinds. Unstippled parts are light-colored zones. This is diagrammatic and general only and not according to scale, elevation, and structure.

marth column, Fig. 2) are the brownish, dusky, dinosaur-bearing beds of the Hell Creek formation (Upper Cretaceous), which dip under the river about 6 miles south of Yule. This marks a point on the Cretaceous-Paleocene boundary. There the upper coal-barren strata of the Hell Creek give way conformably to an overlying lignitic sequence called the Ludlow formation, which is also dusky but with a bluish gray cast. Two miles beyond Yule, northward, the lighter-colored Tongue River member of the Fort Union covers the Ludlow and eventually passes into and under the 350 feet of almost horizontal sandstones, shales, clays, and coals, cropping out on the slopes of Sentinel Butte.

The latter, somber-colored sequence of strata was originally regarded by A. G. Leonard as a dark, upper part of the Fort Union formation and was called the Sentinel Butte group of lignite beds. Leonard (1908, p. 61, Pl. 8, Fig. 1; 1909, p. 20) included in this group the 60–80 feet of hard, gray, brown-weathering sandstone that makes a precipitous cliff not only around the rim of this mesa but of others in the region and that underlies the 40 feet of greenish conglomerate and platy white strata capping the mesa and containing fish remains said to be of White River (Oligocene) age. He said nothing about the relationship of this sandstone to the underlying lignitic strata, but C. A. White (1883, pp. 412, 413), discussing the geological section at Sentinel Butte, said that the relationship is one of conformity. White intimated, however, that the sandstone is younger than the lignitic beds and may represent the Wasatch formation. C. J. Hares (1928, p. 39) was apparently the first geologist to differ from this view, saying

> . . . The member [Sentinel Butte shale] is overlain by the massive sandstone, of probable Oligocene age, that caps the high buttes and probably lies unconformably upon the Sentinel Butte shale.

The writer examined the situation on July 7, 1947. A side road branches from the township road leading south from town and heads toward the top of Sentinel Butte. Just southeast of the point where this road makes a sharp turn, conforming to a reentrant in the north face of the butte, is a steep, talus-covered slope inclined toward a nose in the rim rock. There the red clinkered uppermost sandstone of the lignitic series is distinctly channeled and can be seen to be unconformably overlain by the massive, coarse, brownish gray, cliff-making sandstone, which, at one point in a sag, seems to have been slightly clinkered also. The unconformity is undulatory, with a thin, cream-colored clay locally intervening between the two sandstones. Specimens of the typical Fort Union flora occur in the underlying clinkered sandstone and shale, but there seem to be no fossils of any kind in the overlying massive sandstone. The youngest part of the latter is overlain by greenish conglomeratic beds, better developed on Flattop or Square Butte 8 miles east, where the writer found teeth and other vertebrate remains of Oligocene age. Therefore, except that it appears to be definitely post-Paleocene, the massive sandstone may, on the evidence so far uncovered, be of Eocene or Oligocene age.

PREVIOUS CORRELATIONS

Presumably on the resemblance in color and on the supposed relatively similar corresponding stratigraphic position above the Tongue River member of the Fort Union formation, Thom and Dobbin (1924, Fig. 2, pp. 484, 495; table 2, p. 498) correlated the Sentinel Butte shale with the Intermediate coal group (Taff, 1909, p. 130) and Kingsbury conglomerate on the east side of the Bighorn Mountains in Wyoming and, because the Kingsbury had by that time been suspected of being Eocene in age, expressed the opinion that the Sentinel Butte shale might also be of that age and equivalent to what was generally called Wasatch in other areas. Here, parenthetically, it may be pointed out that Thom and Dobbin (table 2, p. 498) also correlated the Sentinel Butte shale with the "Clark Fork beds" of the Bighorn Basin, but the "Clark Fork beds," on the basis of mammalian remains, are now regarded not as Eocene, but as the uppermost strata in the Paleocene series in that basin.

Although Thom and Dobbin, followed by Hares (1928), designated the Sentinel Butte shale as Fort Union(?), their opinion favoring a Wasatch (Eocene) age was so persuasive that Seager (1942), Hennen (1943), and others accepted the latter age assignment without question. A recheck in July, 1947, of some of Hennen's observations in western North Dakota by the writer and William E. Benson, also of the United States Geological Survey, prompted the present discussion concerning the correlation of the Sentinel Butte shale and its relation to the long-standing problem as to the position of the Paleocene-Eocene boundary in the Rocky Mountains and Plains region. Benson,[3] as a result of detailed mapping in the Knife River area in 1946, had concluded tentatively that the previous regional correlations needed clarification because he found it impossible to distinguish from one another the sequences of strata that had there been called Tongue River member and Sentinel Butte shale. The fossil plants from these beds, submitted to the writer, proved to be Paleocene assemblages, and Benson, therefore, suggested that the Paleocene-Eocene boundary be sought at the top of or above the beds identified as Sentinel Butte shale.

Hennen's work is summarized in a cross section (1943, Fig. 1, p. 1572) based on 13 columnar sections and well logs distributed from Sentinel Butte to Bismarck, North Dakota, and in a structure map (1943, Fig. 2, p. 1584). The key bed by which the sections were correlated is a "marker-bed" described as

> grayish white, flaggy to shaly sandstone, apparently containing a mixture of volcanic ash, with silicified fossil plant stems in abundance, and here and there silicified stumps of trees 3–5 feet in diameter.

This "marker-bed" was designated as Sandstone 21 and was said to occur at a level varying from 25 to 90 feet below the top of the Fort Union formation of Hennen, that is, the base of the Sentinel Butte shale member. Hennen admits (1943, p. 1570) the presence of other similarly silicified stump-bearing zones in

[3] Personal communication.

western North Dakota, although higher stratigraphically, but he gives no inkling that still other zones occur, lower stratigraphically. Actually, such zones are found throughout the entire lignitic series. For a full discussion of these siliceous beds and their distribution the reader should consult Hares (1928, pp. 34–36). The megascopic fossilized plant debris in these beds includes chiefly roots and stumps of trees and suggests strongly that the beds are silicified soils or swamp mucks. As such, if silicifying conditions had been favorable, the top or bottom of every incipient coal seam might have been a likely possibility for the development of such a bed.

Aware of the foregoing facts, the writer and Benson approached a field check of Hennen's conclusions with considerable skepticism, which they found was justified. In the vicinity of Sentinel Butte, Hennen's "marker-bed" can be seen at about 35 feet beneath the base of the prominent clinker just north of U. S. Highway 10, which, 1 mile east of town, passes close to a clinker-capped conical hill with the silicified zone about midway up the slope. This prominent and persistent clinker in the Fort Union formation is at the local contact between the light-colored Tongue River member and the darker Sentinel Butte shale member, making it a good key-bed in the Sentinel Butte-Medora region. It can be traced eastward and southeastward for many miles as it dips gently toward the Little Missouri River, and Hennen's "marker-bed" just below can be followed eastward into the hills north of the entrance gate to Meyer's ranch, 2.8 miles west of Medora. Traced around to Medora and southeastward on the country road to Sully Springs, the clinker passes under the road about 3 miles west of Sully Springs Station and at that point is underlain by fossil wood. The zone of silicified stumps identified by Hennen (1943, pp. 1570, 1577) as his "marker-bed" crops out 2 miles farther east near Sully Springs Station. This zone, however, is about 85 feet above the clinker marking the Tongue River-Sentinel Butte contact rather than 35–40 feet below it. Therefore, it would seem that, between Sentinel Butte and Sully Springs, Hennen confused two silicified zones in an interval of 100–125 feet. The matching of the beds between the Meyer's ranch locality and Sully Springs is simplified by the presence of a persistent brown zone near the top of the Tongue River sequence.

It seems likely that the zone of silicified wood cropping out near the east gate to South Roosevelt Park on U. S. Highway 10 is the same as the higher one at Sully Springs. From this point eastward and northward, however, one runs into increasing difficulties in attempting to identify and correlate clinkers, coals, and silicified zones across terrane with poor exposures, so that by the time Almont, Bismarck, Sanish, and Williston are reached any reconnaissance correlation is pretty well compounded with guesswork. The best that can be said for any silicified "marker-bed" is that it may be useful locally but can not be relied on across long, concealed intervals. Some coal seams are evidently of wide, lateral extent, but beyond the points where they finger out or across large covered or eroded intervals no apparently correlative seams can be certainly tagged as being at exactly the same stratigraphic levels, that is, as being the same seams.

The dark Sentinel Butte shale, according to Hennen, extends eastward across the Little Missouri River as far as Almont, about 115 miles from Sentinel Butte. Northward it comprises the higher strata of the badlands along the Little Missouri River and is part of the type section of the Fort Union formation on the north side of the Missouri River opposite the mouth of the Yellowstone River. Its color in these farther areas, however, is relatively light, so that in this respect it is practically indistinguishable from the underlying Tongue River member.

### UNITS OF PALEOCENE SERIES

The lignitic sequence underlying the Sentinel Butte shale, about 1,376 feet to the base of the Paleocene at Sentinel Butte, thickens to 1,466 feet at Dickinson and then thins eastward to about 600 feet near Almont. Southward from Sentinel Butte toward Marmarth this lignitic unit also thins to about 900 feet. Apparently most of the thickening and thinning is at the expense of the so-called light-colored Tongue River member. As there is no evidence of unconformity at either the base or top of the Tongue River, its eastward thinning may mean simply that it was never thicker in that area. In some areas, however, the variation in thickness is caused by the lateral transition of light-colored into darker strata and *vice versa* which moves the color boundaries up and down in the section.

This observation introduces a necessary discussion of the vertical and lateral color changes in the northeastern part of the late Cretaceous and early Tertiary lignitic terrane of the Rocky Mountains and Plains, and their effects on the identification, correlation, and mapping of strata. In general, the Hell Creek formation, wherever exposed, has a dusky color tinged with brown, but in some localities displays lighter-colored streaks. The overlying Tullock formation in its type region southwest of Forsyth, Montana, is light-colored and readily distinguishable from the Hell Creek formation below and the dark Lebo member of the Fort Union above. Farther east, however, both boundaries become vague as the Tullock becomes darker until in the region of Ekalaka, Montana, and western North and South Dakota it can scarcely be separated on a color basis from those units. In the vicinity of Glendive, Montana, the Tullock is actually darker (Fig. 3) than the Hell Creek because it contains many closely spaced, thin seams of coal, whereas a great thickness of the upper part of the Hell Creek is coal-barren. The chief distinction between the two is, of course, paleontological, the Hell Creek containing dinosaurs and a Cretaceous flora and the Tullock containing no indigenous dinosaurs but a Paleocene flora.

The Lebo member, at its type section east of the Crazy Mountains, Montana, is grayish green, with much andesitic material. Eastward it becomes darker and at Rosebud (Pierce, 1936, p. 59) and Miles City, for example, is in strong contrast with the lighter Tullock formation below and Tongue River member above. Its boundaries, however, still farther eastward, become less and less sharp, until in the region of the Montana-North Dakota-South Dakota line it merges with the Tullock to become the Ludlow formation, a mixed light and dark sequence whose

upper boundary passes imperceptibly into what has been mapped as the Tongue River member. Interfingering with the Ludlow from the east are tongues, probably representing brackish estuarine deposits, of the brown, marine Cannonball formation (see Sentinel Butte-Marmarth column, Fig. 2). These can be seen in the bluffs along the Little Missouri River just south of Yule. The oyster bed has been known since its discovery by Leonard in 1907, but the corbula bed, discovered by the writer in 1931, now receives its first published notice.

FIG. 3.—Badlands 6 miles southeast of Glendive, Montana. Arrow points to Cretaceous-Paleocene boundary with Hell Creek formation below and Fort Union formation above. Here, Fort Union is somewhat darker than Hell Creek. August 2, 1947.

The Tongue River member of the Fort Union in the type exposures along Tongue River in Wyoming and Montana is essentially a light-colored zone of sandstones, shales, clays and coals. Duller colors, however, prevail in its southwestern and northeastern extensions, and lenses or bands of darker-colored portions come and go both vertically and laterally, so that its boundaries, except locally, are very indefinite, accounting perhaps for many of the variations in thickness attributed to the member. Southwest of Broadus, Montana, a considerable dark sequence, near the top of the Tongue River but beneath lignitic strata containing Wasatch fossils appears to the writer to be correlatable northeastward with the dark Sentinel Butte shale and its lateral equivalents.

In brief, the color changes match the equally great variations in lithologic composition, vertically and laterally, in the Paleocene sequence east of the Rocky Mountains, and render the definition and mapping of its several so-called members difficult or impossible, except locally. No reliance can be placed on distant lateral correlations made on this basis. Furthermore, except for the Cannonball

formation with its marine and brackish-water fossils, the fresh-water members can not be separated satisfactorily from one another by means of their plant fossils, which, however, are of great importance in distinguishing the Paleocene from the Cretaceous and Eocene, and the early from the late Paleocene.

### UNITS OF EOCENE SERIES

The broad but shallow synclinal basin east of the Little Missouri River has preserved along its axis the youngest strata of the lignitic sequence. These consist of coal seams and light-colored sandy beds which can be seen in the vicinity of Richardton, Hebron, the Killdeer Mountains, and Grassy Butte, North Dakota. Locally, these strata are unconformable on the underlying Sentinel Butte shale. Early in July, 1947, Benson and party discovered specimens of the floating fern *Salvinia preauriculata* Berry in the basal beds, thereby proving their Eocene age. Fragmentary, but not distinctive, dicotyledonous leaves, as well as some fossil wood, and a small piece of bone have also been found in them, and locally the beds are conglomeratic. The exact areal definition and distribution of these beds will probably be incidental to mapping now being done by Benson, or by Benson and Laird, who propose that the beds, hitherto referred to in the literature as the "Unnamed member of the Wasatch," be called the "Golden Valley formation" (Benson and Laird, 1947) from typical outcrops just west of Golden Valley, North Dakota.

Although the writer has been studying the Paleocene formations of the Rocky Mountains and Plains for many years, he has never found any *Salvinia* in them. Specifically, he has not found *Salvinia* or any other plant and animal evidence of Eocene age in the Sentinel Butte shale and its lateral equivalents, despite extended search for such evidence. The lone mammal fossil, *Titanoides primaevus* Gidley, found near Buford, North Dakota, in the Sentinel Butte shale portion of the type section of the Fort Union formation, is regarded as of late Paleocene age. All the fossil plants of the Sentinel Butte shale and its lateral equivalents appear to be Fort Union species. The conclusion seems certain that the Sentinel Butte shale, on both paleontologic and stratigraphic grounds, belongs with the Paleocene sequence.

On the east side of the Bighorn Mountains, Wyoming, in the region of Sheridan, Buffalo, and southeastward, a 2,000-foot sequence of Fort Union strata is unconformably overlain by a thick conglomerate called the Kingsbury conglomerate (Brown, 1948), whose eastward stringers finger out into lignitic and variegated Wasatch strata in the Powder River Basin. These strata contain an early Eocene fauna (*Hyracotherium*, *Diacodexis*, and *Coryphodon*) and flora (*Salvinia* and others). Taff (1909) divided the lignitic sequence along the mountain front near Sheridan into lower and upper members, fixing upon the Carney coal bed as the dividing line. The lower member, estimated to be 2,500–2,800 feet thick, undoubtedly included some basal Fort Union (Paleocene) but was chiefly Lance (Upper Cretaceous). The upper member, estimated to be not less than

2,200 feet thick, was divided into a Tongue River coal group, Intermediate coal group, and Ulm coal group. Specific reasons for this division were not stated, except that the Intermediate coal group was described as consisting chiefly of shale and sandstone with few workable coal beds, and the Roland coal bed, just below its base, was assigned to the top of the Tongue River coal group. The Kingsbury conglomerate, cropping out farther south beyond the Sheridan field, was said to occupy a position somewhere laterally of the Intermediate coal group with stringers into that group. However, neither Taff nor anyone else has succeeded in tracing the Roland coal southward beyond Sheridan and in establishing its stratigraphic level relative to the base of the Kingsbury conglomerate. No paleontologic evidence has been found in the strata immediately adjacent to the Roland coal seam to suggest that it marks the top of the Paleocene series. On the contrary, in the lignitic area east and northeast of Buffalo, and near Quietus, Montana, at levels from 200–250 feet above what has there been called the Roland coal, the writer has found *Salvinia preauriculata*—the first occurrences in the Tertiary lignitic sequence. Furthermore, the fresh-water invertebrates, according to identifications in an unpublished paper by T. C. Yen, suggest that the first notable change in faunal composition is in the vicinity of the Arvada coal bed, about 200 feet above the Roland coal in the Powder River coal field east of Sheridan. This level would be nearly correlative with that of a 5-foot unnamed local coal seam (Taff, 1909, Pl. 8) near the top of the lower half of Taff's Intermediate coal group—a horizon that should be prospected carefully for evidence of unconformity and conglomeratic materials, as it seems to the writer to be at about the right level for the base of the Kingsbury conglomerate and the base of the Eocene series.

That the Sentinel Butte shale is equivalent to the upper part of the Paleocene sequences on Bear Creek, near Red Lodge, and on the east side of the Crazy Mountains, Montana, is probable, but not demonstrable at the present time. The Crazy Mountain Fort Union section, according to Simpson (1937, p. 15), comprises 1,350 feet of Lebo and 5,000 feet or more of "Melville." Concerning the "Melville," Simpson is certain only of the Paleocene age of the lower 3,000 feet, which contains identifiable early upper Paleocene mammals. Beneath the Lebo and above the Hell Creek is a 500-foot zone of sandstones and shales called "Bear" by Simpson and designated Fort Union(?). The lack of dinosaurs and the presence of Tullock types of plants, found by the writer and A. C. Silberling in 1936, indicate that most or all of the "Bear" belongs with the Fort Union sequence. This brings the total Paleocene section to 5,000 feet or more, certainly enough to include the lateral equivalents of the Sentinel Butte shale.

## CONCLUSION

All the recent paleontologic and stratigraphic evidence points toward retention of the Sentinel Butte shale within the Fort Union formation of the Paleocene series. This evidence appears to be harmonious across the entire Paleocene-Eo-

cene terrane east of the Rocky Mountains and permits the drawing of the Paleocene-Eocene boundary with reasonable assurance.

REFERENCES CITED

BENSON, W. E., AND LAIRD, W. M. (1947), "Eocene in North Dakota," *Bull. Geol. Soc. America*, Vol. 58, pp. 1166–67.

BROWN, R. W. (1948), "The Age of the Kingsbury Conglomerate Is Eocene," *Bull. Geol. Soc. America*. In press.

HARES, C. J. (1928), "Geology and Lignite Resources of the Marmarth Field, Southwestern North Dakota," *U. S. Geol. Survey Bull. 775*.

HENNEN, R. V. (1943), "Tertiary Geology and Oil and Gas Prospects in Dakota Basin, North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 12, pp. 1567–94.

LEONARD, A. G. (1908), "The Geology of Southwestern North Dakota with Special Reference to Coal," *North Dakota Geol. Survey 5th Bienn. Rept.*, pp. 27–114.

LEONARD, A. G., AND SMITH, C. D. (1909), "The Sentinel Butte Lignite Field, North Dakota and Montana," *U. S. Geol. Survey Bull. 341*, pp. 15–35.

PIERCE, W. G. (1936), "The Rosebud Coal Field, Rosebud and Custer Counties, Montana," *U. S. Geol. Survey Bull. 847-B*.

SEAGER, O. A., ET AL. (1942), "Stratigraphy of North Dakota," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 8, pp. 1414–23.

SIMPSON, G. G. (1937), "The Fort Union of the Crazy Mountain Field, Montana, and Its Mammalian Faunas," *U. S. Nat. Mus. Bull. 169*.

TAFF, J. A. (1909), "The Sheridan Coal Field, Wyoming," *U. S. Geol. Survey Bull. 341*, pp. 123–50.

THOM, W. T., JR., AND DOBBIN, C. E. (1924), "Stratigraphy of Cretaceous-Eocene Transition Beds in Eastern Montana and the Dakotas," *Bull. Geol. Soc. America*, Vol. 35, pp. 481–506.

WHITE, C. A. (1883), "On the Existence of a Deposit in Northeastern Montana and Northwestern North Dakota That Is Possibly Equivalent with the Green River Group," *Amer. Jour. Sci.*, 3rd Ser., Vol. 25, pp. 411–16.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1275-1291, 10 FIGS.

# GEOLOGICAL OBSERVATIONS ON CURAÇAO, N.W.I.[1]

H. P. SCHAUB[2]
Havana, Cuba

## ABSTRACT

The paper deals with the geological history of the island of Curaçao in the Lesser Antilles. The Pleistocene coral limestones and the outstanding dip slopes formed by them are discussed and the conclusion is reached that the dip slopes represent the original dip of coral reefs rather than evidence of folding. Several stages of uplift and subsidence are connected with the formation of the coral limestones. Two upper Eocene formations, one of them new, are described, and finally an attempt is made to correlate the geological histories of Curaçao and western Venezuela.

## INTRODUCTION

The geology of Curaçao has always attracted the interest of visiting geologists. On its small surface at least seven sedimentary formations ranging from the Cretaceous to the Holocene can be observed overlying a crystalline core formed mainly of diabase. All of them are transgressive and represent stages of submergence following long periods of uplift. In part they are strongly folded and intruded by small veins and plugs of igneous rocks. The most recent geologic history includes the formation of coral reefs, several stages of uplift and subsidence which resulted in the formation of sea-cut terraces and of wide, drowned valleys forming beautiful lagoons and excellent harbors. These phenomena are so obvious that they strike the eye even of the casual observer.

The following stratigraphical sequence was established by former observers, mainly by G. J. H. Molengraaff (1) who mapped the whole island.

| | | |
|---|---|---|
| HOLOCENE | Asiento formation | Sub-Recent coral beds formed in lagoons of island and lifted about 6 meters above present sea-level |
| | Subsidence | Valleys formed during preceding period of erosion are drowned and become wide lagoons and bays |
| | Uplift | Island rises at several intervals evidenced by sea-cut terraces at different levels. Erosion formed wide, dendritic valleys in easily weathering diabase of core of island which reach sea through narrow gorges cut into more resistant Seroe Domi limestones |

[1] Published with permission of Bataafsche Petroleum Mij., The Hague, Netherlands. Manuscript received, April 16, 1948.

[2] Geologist, Cia. Petrolera La Estrella de Cuba.

In January and June, 1946, the writer spent a total of 3½ weeks on Curaçao, Netherlands West Indies. During this time he made some geological observations on the island which are described in the following notes. He is indebted to Frater Realino of the St. Thomas College in Willemstad who accompanied him on several occasions and drew his attention to some areas of geological interest, and to N. van Meteren of Willemstad who guided him to Seroe Mainsjie.

The writer wishes to thank W. Mohler, Basel, for study of the larger Foraminifera from Seroe di Cueba, and F. G. Keyzer, Havana, for his contributions to this paper which include investigation of the microfaunas found in the Mainsjie formation and critical discussion of the manuscript.

| | | |
|---|---|---|
| PLEISTOCENE | Seroe Domi formation | Coral limestones overlying all older formations with basal conglomerate |
| PLIOCENE<br>MIOCENE<br>OLIGOCENE | Missing | Gap may be due to erosion, more probably to non-deposition. Slight folding occurs during this period |
| UPPER EOCENE | Seroe di Cueba formation | Fossiliferous limestones with rich fauna of larger Foraminifera. Transgressive on diabase |
| ? | Folding and uplift | Intense folding followed by erosion. Intrusive activity proved by the occurrence of albitite sill in middle Curaçao formation (2) |
| ? | Middle Curaçao formation | Conglomerates, sandstones, shales, marls with thin limestone beds and concretions. Fossil evidence poor. Conglomerates contain pebbles of diabase, chert, and Seroe Teintje limestone as well as rocks not derived from Curaçao |
| ? | Uplift and erosion | |
| UPPER SENONIAN (Campanian or Maestrichtian) | Seroe Teintje formation | Reef limestone containing corals, *Lithothamnium* and rudists. Transgressive on diabase and Knip formation |
| ? | Uplift and erosion | |
| ? | Knip formation) (western Curaçao)<br>Ronde Klip formation (eastern Curaçao) | Cherts and tuffs overlying diabase.<br>Tuffogene foraminiferal limestones and foraminiferal tuffs.<br>Age not determined by fossil evidence |
| LOWER CRETACEOUS or PRE-CRETACEOUS | Diabase | "Basement" of island, probably of volcanic origin. Age not determined |

The observations presented herewith refer mainly to the coral limestones of the Seroe Domi formation and the process by which they were uplifted, to the Seroe di Cueba formation, and a further Eocene formation not yet described which is called the Mainsjie formation after Seroe Mainsjie in the southeastern part of the island.

## LATE PLEISTOCENE UPLIFT

### GENERAL DESCRIPTION

The geologist visiting Curaçao at once observes a series of hills formed by the coral limestones of the Seroe Domi formation along the southwest coast of the island which show nice dip slopes on their southwest flanks. These are well developed on both sides of the Schottegat. East of the entrance to this bay is the hill on which Fort Nassau is situated above such a dip slope. At the west the hills called Seroe Domi, Zwarte Berg, Veerisberg (Figs. 2 and 6), and Jack Evertsberg (west of Piscadera Bay) expose dip slopes dipping approximately south-southwest

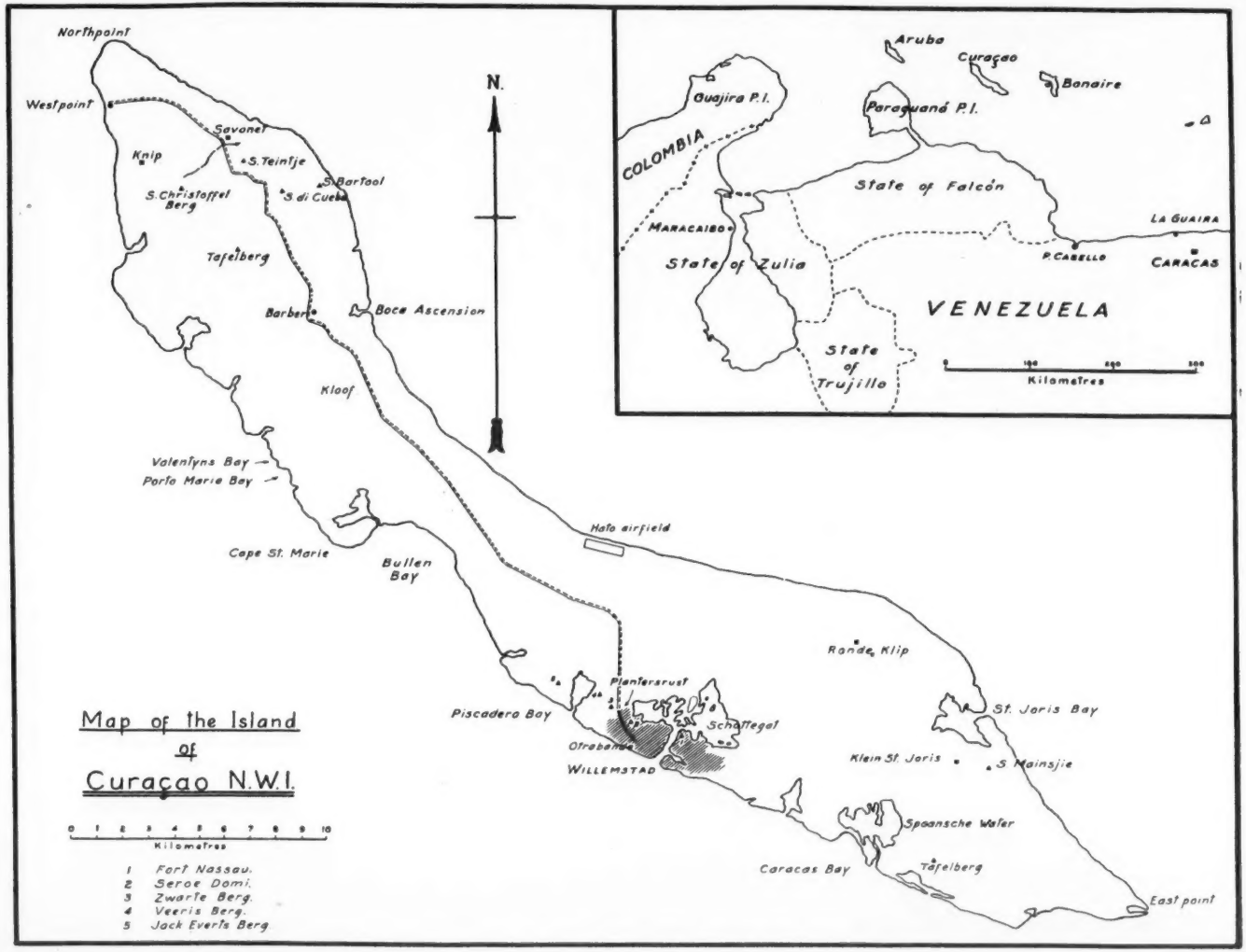



FIG. 1.—Map of island of Curaçao and key map showing position of Curaçao north of Venezuela.

(toward the coast). Similar hills extend nearly as far as the eastern tip of the island, though east of the Tafelberg (southeast Curaçao) they are much lower than around Willemstad. Well developed dip slopes can also be seen around Cape St. Marie (northwest Willemstad) (Fig. 3).

The first and obvious conclusion seems to be that the uplift which raised these coral limestones above sea-level was accompanied by folding which tilted the beds of the Seroe Domi formation considerably (15–20°). This is the interpretation given by G. J. H. Molengraaff (1), and L. Rutten (3) who illustrates his hypothesis of folding by a series of block diagrams.

Further observation, however, discloses some facts inconsistent with folding. First of all, no dip slopes whatsoever can be observed on the northeast coast of the island, that is, on the flank opposite to the dip slopes on the southwest coast. This might be explained as due to destruction by the strong surf on the northeast coast which is exposed to the open ocean and the trade winds. In fact, the outstanding morphological features on the northeast coast are wide, sea-cut terraces.

Secondly, the dip slopes in the area of Bullen Bay and Cape St. Marie show a strong relation to the present coast line which can easily be recognized in Figure 3. They dip everywhere at right angles to the coast, thus forming a pronounced spur around Cape St. Marie and a syncline around Bullen Bay. Of course, this might be due to folding, the coast line being dependent on the tectonic features. Figure 3 shows, however, that the dip slopes follow also small coastal embayments like Porto Marie and Valentyns Bay. It seems thus more probable that the coast line as well as the dip slopes are dependent on the shape of the pre-Seroe Domi erosional surface rather than on folding; in other words, that the inclined position of the coral limestones is the original one in which they were deposited.

This hypothesis is confirmed by the fact that the corals, wherever they can be observed in their original place in the limestones, are still standing vertically. This is the case on the northeast as well as on the southwest coast of the island, along the edges of the terraces as well as of the sloping hills. It is a pleasure to note that this observation was made by K. Martin in 1888 (4), who concluded that there was no folding after the deposition of the coral limestones but only uplift.[3] Some supporting evidence can be cited now.

### OBSERVATIONS AT PLANTERSRUST

Plantersrust is the part of Willemstad situated on the main road from Otrabanda to the northwestern half of the island where this road passes between Seroe Domi and Zwarte Berg. K. Martin saw and described some gravel beds in this area along the road. Better exposures are now present in a small gravel pit situated behind the radio station in Plantersrust (Fig. 4). Here it can be observed

[3] The term uplift as used in this paper does not necessarily imply that the island was raised above sea-level by positive movement. The sea-level itself may have been lowered, and there is no way to determine which was the case. Inversely, this applies also to the term subsidence.

FIG. 2.—View northwest from Seroe Domi. Plantersrust is visible at foot of Zwarte Berg. In background, Veerisberg.

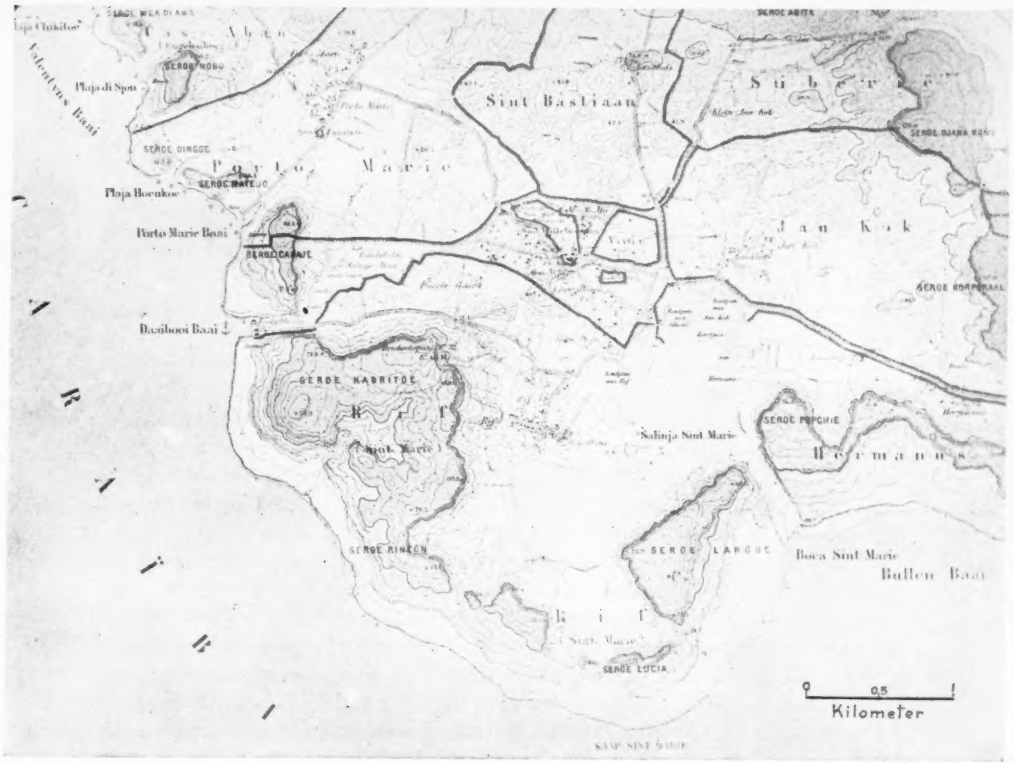



FIG. 3.—Map of Bullen Bay and Cape St. Marie. Reduced from Topographical Map of Curaçao, Sheet VII. Dip slopes of Seroe Domi limestones appear clearly on topographic picture.

that gravels and sands rest unconformably on an irregular surface of strongly weathered diabase which slopes toward the southwest coast. The gravels are badly to well sorted and consist entirely of diabase grains and pebbles which are angular to well rounded. Cross-bedding indicates that the formation was deposited in a delta, and obviously the material came from the interior of the island. All beds contain small balls varying in diameter from 1 to 3 centimeters, which consist of coarse angular grit of diabase slightly cemented by white to colorless, crystalline calcite. They are well rounded but some are grown together. Probably they were formed by deposition of the calcareous cement in the top

FIG. 4.—Gravel pit at Plantersrust. At right very weathered diabase overlain toward center of picture by cross-bedded sands and gravels. Radio tower stands on ridge-forming Seroe Domi limestone. First limestone lenses intercalated between gravels are visible slightly at left below tower.

layer of the delta when little terrigenous material was deposited, for example, during dry seasons. This bed was then broken up before it had hardened much and the pebbles were rolled by the waves until they had the spherical shape.

Upward and coastward the gravels grade into the coral limestones of the Seroe Domi formation which appear first in lenses still containing pebbles of diabase, and replace the gravels gradually.

The gravel beds dip coastward (15°–25°), approximately as much as the surface of the diabase on which they rest. The cross beds, however, dip only slightly (approximately 5°) toward the coast. This means that if tilting had brought the coral limestones and gravels into their present position, the cross-beds would originally have been inclined toward the shore from which the sands and gravels came. This is contrary to any experience of delta formation. It is quite apparent that the gravels exposed at Plantersrust suffered no tilting. Consequently, the overlying coral limestones can not have been folded either.

OBSERVATIONS IN SCHOTTEGAT

On the western bank of the narrow channel which is the entrance to the Schottegat, the main harbor of Curaçao, a fairly thick bed of coral sands can be seen intercalated between the coral limestones (Fig. 5). Limestones and sands alike dip about 25° toward the coast of the island. The sand, however, is also cross-bedded, the cross-beds dipping only about 5° toward the coast. A thin bed of coral limestone overlies the sands with the same inclination. Here also it is obvious that the sands and consequently the limestones were not tilted, since otherwise the cross-beds in the sands would originally, during their deposition, have been inclined toward the island.

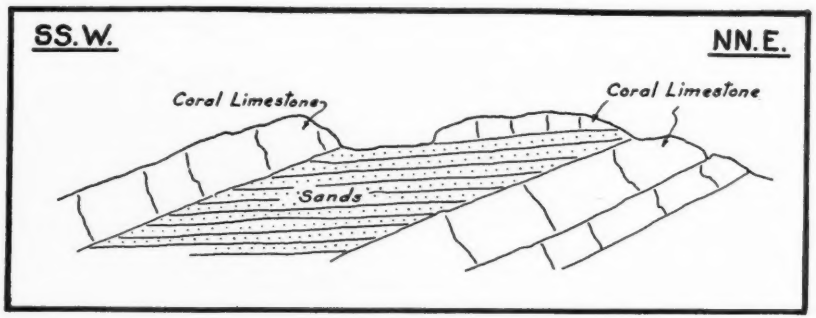



FIG. 5.—Sketch showing observations in Schottegat.

CONCLUSIONS

On the basis of the described observations it must be concluded that no folding occurred after the deposition of the Seroe Domi formation but only an uplift which was, however, considerable. The inclination of the coral limestones is depositional and probably dependent on the shape of the pre-Seroe Domi erosional surface which was gradually overgrown by coral reefs. The total amount of uplift is indicated by the occurrence of coral limestone at an elevation of 229 meters on the Tafelberg in northwest Curaçao. It is probable that the formation of the coral limestones and the uplift took place in several stages.

Subsidence preceding the deposition of the Seroe Domi formation brought the sea-level to approximately 230 meters above its present position. Only the high northwestern part of the island, in the neighborhood of the Christoffelberg, remained emerged during this period. Coral reefs formed around the reduced island but, due to strong erosion subsequently affecting this accentuated region, only the Tafelberg witnesses the stage.

Probably a period of uplift followed during which erosion began to cut valleys into large areas of central and southeast Curaçao. Deltas were formed where the small streams reached the sea and at the same time a rim of corals started to

grow around the island. A period of slow subsidence to a stage at which the sea-level was approximately 140 meters above its present position, followed. The coral fringe along the southwestern coast grew slowly and formed a reef while wave action due to the strong easterly trade winds prevented the formation of such a reef along the northeast coast. The corals, however, grew across the back of the island. Similar conditions can be observed to-day on the neighboring island of Aruba where an active reef exists on the southwest coast which is protected against the trade winds, but not on the open northeast coast.

Indications of a third stage can be observed on the slope of the Veerisberg and the Jack Evertsberg where a second, lower reef seems to overlie the first (Fig. 6). A thinning of these reefs from top to bottom is also apparent.

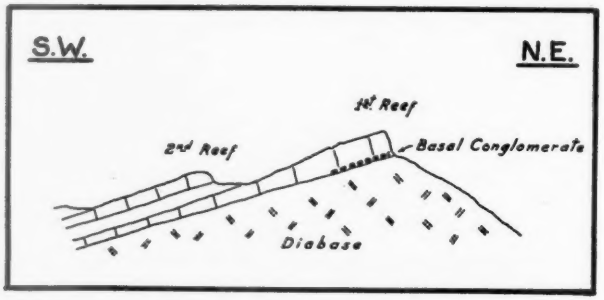



FIG. 6.—Sketched cross section through Veerisberg.

The position of the gravels at Plantersrust is of interest. Plantersrust is situated in a deep gap between Seroe Domi and Zwarte Berg. Here, the growth of the reef was probably hampered by the influx of fresh water from the stream which carried the gravels and sands into the sea, as there is no indication that the hill range was cut by erosion at a later date. Most other gaps in the hill range formed by the old reef are to-day the entrances of the many bays and lagoons of the island. It is thus possible that their position was determined by water courses existing before and at the time of deposition of the coral reefs.

Erosion set in again after a further uplift. Wide, dendritic valley systems were formed behind the gaps in the hill range on the southwest coast. The gaps themselves were much deepened. Most water courses apparently found their way toward the southwest coast, and nearly all large bays and lagoons are situated on the southwest coast while only one, St. Joris Bay, opens on the northeast coast. Even to-day the larger part of the island is drained toward the southwest coast.

The later geologic history of the island includes a further subsidence to approximately 6 meters below the present sea-level during which the lower part of the existing valleys were drowned. Sand and silt were deposited where the shortened rivulets entered the bays. In other parts of the bays, mainly around half-

islands and small islands, the coral limestones of the Asiento formation were formed. A coral rim and reef formed in places along the southwest coast, for example, between Schottegat and Piscadera Bay. On the northeast coast a wide terrace was cut at the same time by wave action (Fig. 7).

An uplift to the present level followed as last move. It resulted in exposure of the Asiento formation. Several bays were severed from the sea and a few shallow ones raised completely above sea-level. Along the northeast coast a new cliff is being cut by the surf.

The Pleistocene and Holocene history of Curaçao as described above is probably not complete. Molengraaff (1) mentions terraces at many different levels, and it is certain that mapping of the morphological features on the excellent topographic map of Curaçao (scale 1:20,000) would provide an interesting account of uplift and subsidence which could possibly be correlated with similar developments on other Caribbean islands and on the Venezuelan main land.

## EOCENE

The upper Eocene Seroe di Cueba formation has been known for some time and was the subject of several publications (1, 7–10) because of its rich faunae of larger Foraminifera. More recently, P. W. Hummelinck collected some fossils at Seroe Mainsjie in southeast Curaçao (5) which were described by C. O. van Regteren-Altena (6)[4] who concluded that they proved the presence of a new formation probably belonging to the lower Eocene. The stratigraphy of this Eocene, however, has not been described so far, and the name Mainsjie formation is proposed herewith for the fossiliferous beds exposed on Seroe Mainsjie.

### SEROE DI CUEBA FORMATION

The Seroe di Cueba formation is exposed on Seroe di Cueba and Seroe Bartool in northwest Curaçao (Fig. 8). It overlies the diabase with a transgression but the contact is hidden everywhere under a thick mantle of débris. The following sequence was observed a little east of point 71.9 m. in a section extending north-northeast across the southwest spur of Seroe di Cueba.
From top to bottom:

| | *Meters* | |
|---|---|---|
| 7. | 25 | Whitish gray limestone containing some grit near base. Larger Foraminifera are fairly common throughout; echinids and pelecypods occur commonly and one big oyster was observed |

[4] The following Mollusca have been identified by van Regteren-Altena:
*Architectonica* spec.
*Ampullina ?* spec.
*Polinices* spec.
*Arca* spec.
*Venericardia parinensis* Olsson
*Cardium* spec.
*Clementia* cf. *parinensis* Olsson
*Tellinidae* gen. spec.
*Raetomya arbolensis falconensis* (Rutsch)

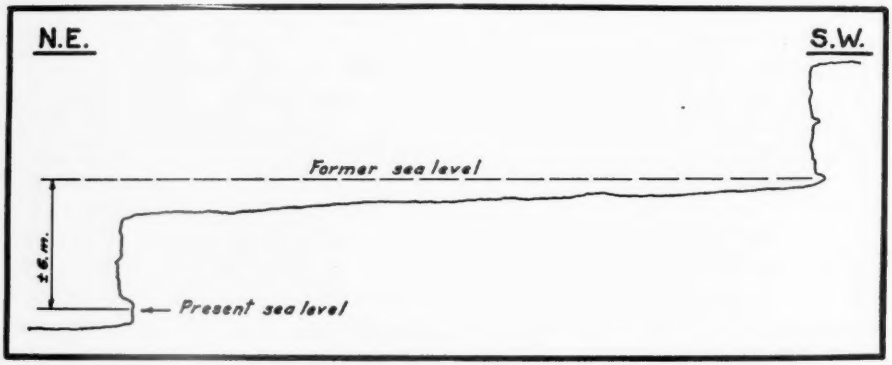



FIG. 7.—Sketch illustrating formation of terraces on northeast coast of Curaçao near Hato air field.

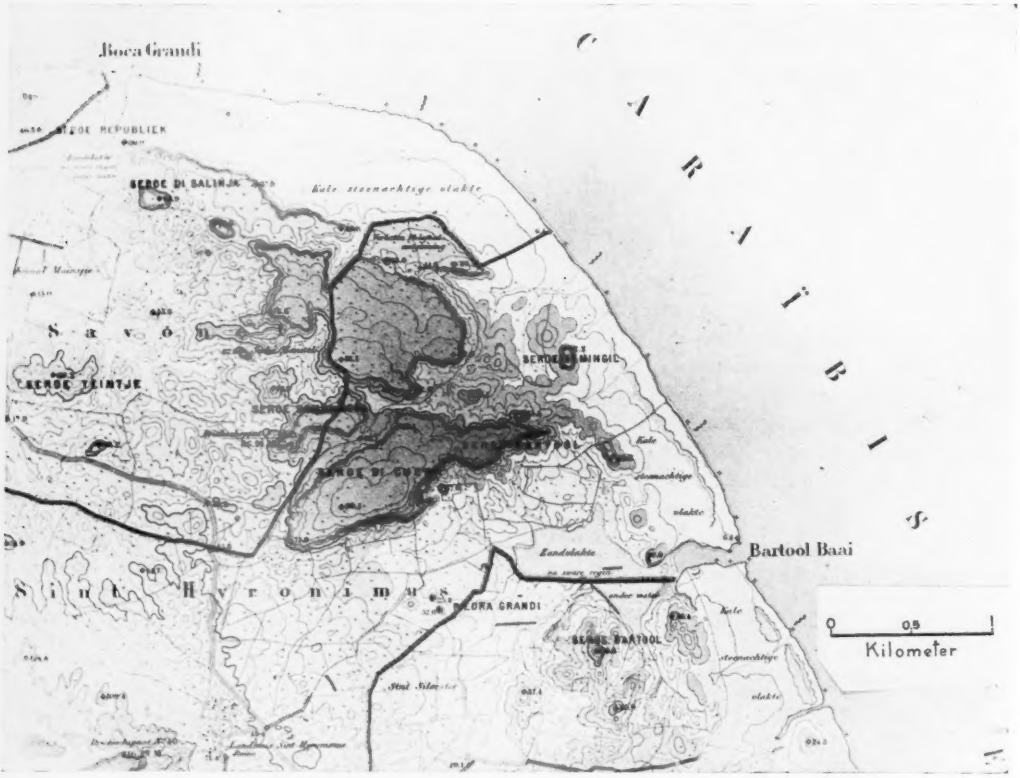



FIG. 8.—Map of Seroe di Cueba area. Reduced from Topographical Map of Curaçao, Sheet III.

| | *Meters* | |
|---|---|---|
| 6. | 5 | Whitish gray, partly oölitic limestone forming small ridge. Uppermost bed (0.3 m.) is hard and forms small dip slope. It is underlain by thin bed consisting nearly exclusively of larger Foraminifera |
| 5. | 14 | Whitish gray limestone containing Foraminifera in irregular layers, and small chert pebbles reaching a size of 1 cm. |
| 4. | 0.5 | Whitish gray limestone nearly wholly composed of larger Foraminifera, pelecypods, and echinid remains. This bed is on crest of hill near point 71.9 m. |
| 3. | 10 | Whitish gray to yellowish, easily weathering limestone and calcareous sandstone, partly conglomeratic with well rounded pebbles rarely bigger than 1 cm. |
| 2. | 0.6 | Conglomerate. Pebbles lie in calcareous cement and consist mainly of weathered diabase, but cherts (Knip formation) and hard, gray limestone (probably Seroe Teintje formation) occur also. Pebbles are well rounded and reach diameter of 5 cm. |
| 1. | 3 | Whitish gray, badly bedded limestone with rare, well rounded pebbles of diabase (maximum size 3 cm.) |

The thicknesses of these beds are estimated only and may be too small. The total thickness of the described section amounts to approximately 58 meters but it is estimated that another 10–20 meters are hidden by débris at the base of the slope of Seroe di Cueba where several big oysters were found. This may indicate the presence of a bed near the base of the formation in which oysters are more common than higher in the section.

The strata dip approximately 20°–30° N.-NW. in the southern slope of Seroe di Cueba. They seem to flatten west of point 90.1 m. and to dip in a slightly southeasterly direction on the northwest slope of the hill, opposite Seroe Bomba Boa. As it is improbable that the high dips mentioned are wholly depositional, it can be concluded that the limestones have been subject to some tilting and folding.

The age of the formation was first determined by R. Koch (7) as lower Oligocene, based on material collected in the western slope of Seroe di Cueba. Material from the southern slope of the hill examined by L. Rutten (8) contained only Eocene faunae. In a second paper, Koch (9) assumes therefore that the limestones reach from the upper Eocene into the lower Oligocene. During a study of the northern slope of the hill by M. G. Rutten and L. W. J. Vermunt (10), only upper Eocene faunae were found. Three faunas collected by the writer in beds 4, 6, and at the top of bed 7 (see preceding section) were reviewed independently by W. Mohler and F. G. Keyzer who come to the conclusion, namely, that they belong to the upper Eocene and contain the same species as those described by Rutten and Vermunt. As they were collected on the western side of Seroe di Cueba and are well distributed through the section forming this part of the hill, there is thus no reason to assume that the Seroe di Cueba formation extends into the lower Oligocene. It belongs entirely to the upper Eocene (Jacksonian).

### MAINSJIE FORMATION

On the north flank of Seroe Mainsjie below triangulation station No. 8 (Figs. 9, 10) the following sequence can be observed overlying the diabase.

From top to bottom:

| | *Meters* | |
|---|---|---|
| 4. | 20 | Light gray, yellow-weathering, slightly silty, calcareous and bentonitic clays which contain a fauna of very small, dwarfed, calcareous Foraminifera and echinid spines. |

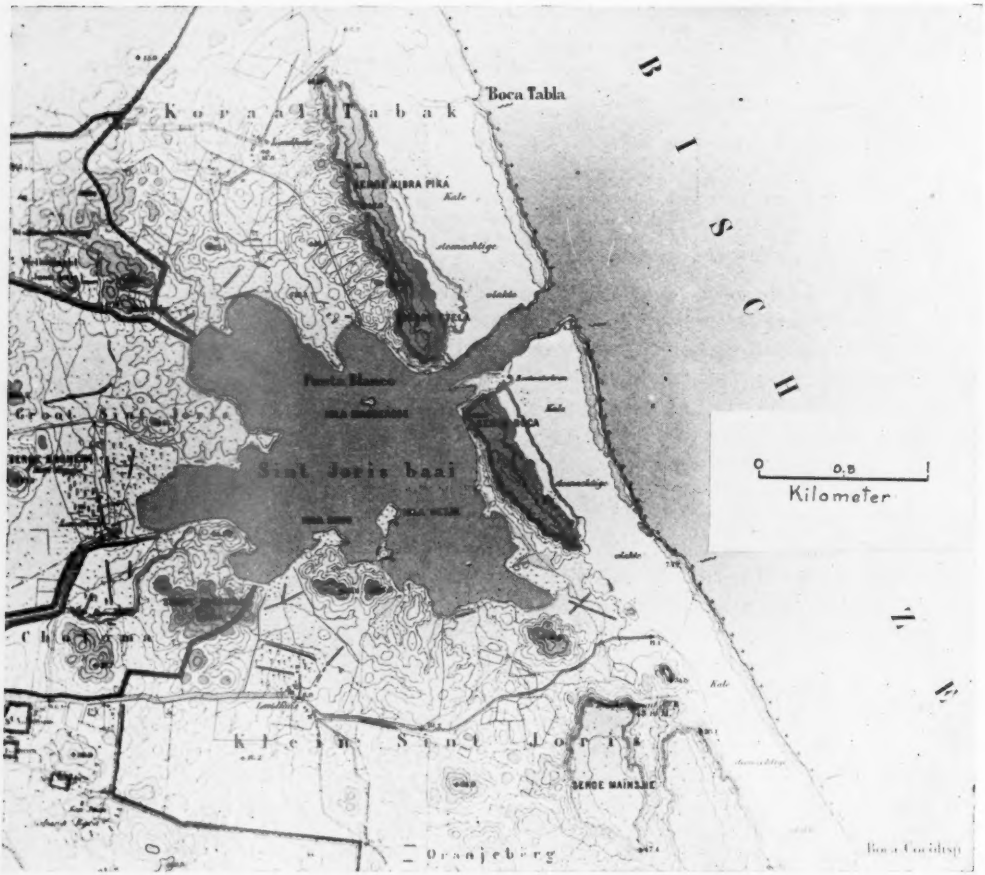



FIG. 9.—Map of St. Joris Bay showing position of Seroe Mainsjie. Reduced from Topographical Map of Curaçao, Sheet XIV.

FIG. 10.—View of Seroe Mainsjie from north-northwest. Low hill behind car consists of diabase. Outcrops of beds 1–3 were observed above two windswept isolated bushes in center of picture. Bed 4 forms slopes on right side of hill. Top of hill consists of coral limestones.

| *Meters* | | |
|---|---|---|
| | | Some beds of soft, lensing, calcareous sandstones changing laterally into gray, concretionary limestones are intercalated in clays. These beds are in places full of fossils which are preserved in sandstones as casts unless they belong to some thick-shelled species, while small, thin shells are found in limestones. Fossils described by C. O. van Regteren-Altena are derived from the sandstones which also contain microfauna including many specimens of *Camerina moodibranchensis* Gravell and Hanna. Many small, subangular to well rounded grains of dark green diabase occur in sandstones |
| 3. | 0.3 | Calcareous sandstone and conglomerate with well rounded pebbles of weathered diabase reaching a diameter of 2 cm. Some badly preserved macrofossils. Hard, resistant bed which is composed of 5 cm. sandstone at top and bottom, 20 cm. conglomerate in center |
| 2. | 0.2 | Hard, light brown to yellow, fine-grained, calcareous and micaceous sandstone. Two beds of 10 cm. each. Bedding planes are very micaceous. Sandstone contains few fossil remains |
| 1. | 2 | Calcareous breccia composed of angular to subangular pebbles of weathered diabase and many worn shell fragments of 2–10 mm. diameter |

Diabase

The outcrops are unfortunately not continuous and the contact between diabase and Seroe Mainsjie formation is not exposed. There can be little doubt, however, that the described strata lie with a transgression on the diabase. The thickness of bed 4 is estimated only due to lack of time. The total thickness of the Mainsjie formation must amount to 40–50 meters at least. These beds dip approximately 20° N.-NE., and are unconformably overlain by coral limestones of the Seroe Domi formation which form the flat top of Seroe Mainsjie and contain some pebbles of the Mainsjie formation at their base.

A second occurrence of the Mainsjie formation was discovered at Kloof in northwest Curaçao. Kloof is a steep ravine about 4 kilometers south-southeast of the village called Barber. It is cut into the coral limestones of the Seroe Domi formation and underlying beds and is passed by the main road from Willemstad to Westpoint (Fig. 1) in a steep descent from the coral plateau of central Curaçao into the valleys draining toward Boca Ascension.

In this ravine it can be observed that the coral limestones are underlain by soft, fine-grained, dark gray, yellow-brown-weathering, calcareous and nearly non-bedded sandstones which have a very salty taste and contain badly preserved shells of small Lamellibranchia. Some slightly harder beds indicate the dip, which is approximately 5° S.-SE. The thickness of the sandstones can not be measured but is estimated to amount to 10 meters at least. The relation of the sandstones to older formations is not exposed but, as they consist mainly of weathered diabase material, it can be assumed that they overlie the diabase with a transgression.

Based on his field observations, the writer thought that these sandstones belonged to some Pleistocene delta formation similar to the one observed at Plantersrust, because a small outcrop of coarse gravels and sands can be seen at the bottom of the Kloof ravine, 200 meters north-northwest of the sandstones. The pebbles of the conglomerate, which reach a diameter of 20 cm., consist mainly of chert from the Knip formation.

The credit of proving that the sandstones exposed at Kloof are most probably

part of the Mainsjie formation goes to F. G. Keyzer who insisted on washing the sandstones and discovered a Mainsjie fauna including two specimens of an *Operculina*. Although this fauna is not as well preserved as the one found at Seroe Mainsjie itself and is considerably poorer in species, there is so far no reason to assume that it has been reworked or belongs to a different formation.

The following is the result of Keyzer's preliminary paleontological investigation.

Well preserved smaller Foraminifera are present in the clays of bed 4 at Seroe Mainsjie. From 14 species provisionally identified, 9, possibly even 11, seem to be identical with forms described by P. J. Pijpers (11) from the upper Eocene of Bonaire. The fauna is somewhat dwarfed and deposited under different ecologic conditions than the Bonaire fauna. Typical lower Eocene species which might be expected if C. O. van Regteren-Altena's age determination were correct, are absent.

An abundance of *Camerina moodibranchensis* Gravell and Hanna occurs in a sample of soft sandstone from the same locality. This is a typical upper Eocene (Jackson) form. The species described by Rutten and Vermunt (10) from the upper Eocene of Seroe di Cueba are conspicuously absent in the Seroe Mainsjie formation, as could be verified by comparison with material from Seroe di Cueba. Whether this is only due to facies influences or to a difference in age can not be judged without a larger suite of species permitting a closer age determination of the Seroe Mainsjie formation.

The fauna from Kloof is less well preserved and consists of a smaller number of species than the Seroe Mainsjie faunas. The species agree so much with those from Seroe Mainsjie, however, that there is no reason not to assume the same age for both deposits. One small fragment of *Discocyclina?* was noted. A species of *Operculinoides* could not be identified.

Keyzer concludes that the faunal evidence from Seroe Mainsjie and less so from Kloof strongly points to an upper Eocene (Jacksonian) age.

It is hoped that examination of more material will corroborate Keyzer's conclusions. Meanwhile the writer considers that the Foraminifera provide better evidence than the macrofossils determined by C. O. van Regteren-Altena (6) which are none too well preserved, and that an upper Eocene (Jacksonian) age can be assumed for the Mainsjie formation.

The relation between the Mainsjie and Seroe di Cueba formations is not yet ascertained. The distance between Seroe di Cueba and Kloof is only 8 kilometers, yet facies and fauna of the two formations are very different. It can thus be assumed that they are not quite of the same age although both belong to the Jacksonian. There is little indication which is the older one. Terrigenous material is more abundant in the Mainsjie beds than in the Seroe di Cueba limestones. Since strong orogenic movements followed by erosion occurred before upper Eocene time, it can be supposed that the first formation to be deposited after a renewed advance of the sea would contain more terrigenous material than younger strata. P. J. Pijpers thinks that the upper Eocene marls from Bonaire, which correspond probably with the Mainsjie formation, are older than the limestones occurring on the same island which are closely related faunally with the Seroe di Cueba limestones. However, there is no definite evidence available and the question must be left open.

The rather strong dips observed at Seroe Mainsjie indicate that the formation has been slightly folded before the transgression of the Seroe Domi limestones took place.

### MIDDLE CURAÇAO AND KNIP FORMATIONS

So far the age of neither the middle Curaçao nor the Knip formation has been determined by fossil evidence. The Knip formation is unconformably overlain by the Senonian Seroe Teintje limestone which is dated by coral and rudistid faunae (12, 13), and the middle Curaçao formation contains pebbles of the same limestones and must, on the other hand, be older than the Seroe di Cueba and Mainsjie formations because it has been strongly folded together with Knip and Seroe Teintje formation while the upper Eocene was not affected by this orogenic phase.

The middle Curaçao formation can thus be ranged anywhere between the Senonian and Jacksonian. Lithologically, the formation resembles the middle-upper Eocene of western Venezuela more than the uppermost Cretaceous and Paleocene of the same area. This problem can probably be brought nearer to a solution by searching the middle Curaçao shales for microfaunae which could be compared with those from western Venezuela. In this connection it is interesting to note that orogenic movements are known to have occurred in the upper Eocene in western Venezuela. They were followed by erosion of considerable extent and are witnessed by a transgression at the base of the upper Eocene Paloma Alta formation. These movements correspond possibly with the strong folding which occurred in Curaçao after the deposition of the middle Curaçao formation.

The preceding paragraphs had already been written when Keyzer drew the writer's attention to the following statement by P. J. Pijpers (11, pp. 37 and 38).

> Dr. Trechmann examined some fossils from the midden Curaçao strata, collected by us in East Curaçao. On the strength of some of these fossils he thought it most likely to be of Eocene age.

This seems to confirm the writer's opinion that the middle Curaçao formation belongs to the Eocene rather than to the Cretaceous.

Some of the best exposures of the Knip formation can be observed in Rooi Beroe, a creek in northwest Curaçao (Fig. 1). They consist of thin-bedded, black to yellowish cherts which have a fine-bedded texture and enclose discoidal concretions of 20–30 cm. diameter. The resemblance of these beds with the La Luna formation of western Venezuela is striking though in general the latter is less silicified.

This similarity is of course no proof for a correlation of the Knip cherts and the La Luna formation as it might be due to similar facies conditions only. However, as long as there is no better evidence available it may be used to assign the Knip cherts tentatively to the Turonian-Coniacian which is the age of the La Luna formation according to F. A. Sutton (14).

## CONCLUSIONS

We have seen that a new formation, the Mainsjie beds, must be added to the stratigraphic sequence of Curaçao. The upper Eocene formations have been slightly folded; thus, some orogenic movements must be assumed in the Middle and Younger Tertiary. No folding, however, took place after the deposition of the Pleistocene coral limestones.

It would be interesting to attempt a correlation of the orogenic and epeirogenic movements of Curaçao with those known in the various areas of northern South America, Central America, and the Antilles but this would go far beyond the scope of this paper. Only a short comparison with the geological history of western Venezuela with which the writer is familiar, is given.

In western Venezuela the Cretaceous is transgressive over older formations and the basement. This unconformity corresponds with the transgression at the base of the Knip formation. The phase of uplift, erosion and transgression separating the Knip and Seroe Teintje formations may have its parallel in western Venezuela in a glauconitic horizon at the base of the Colon formation which marks a strong reduction, possibly even an interruption of sedimentation (15, 19). As the Colon formation belongs to the Campanian- lower Maestrichtian according to J. A. Cushman and H. D. Hedberg (16), and the Seroe Teintje limestone is assigned to the same stages, the correlation seems to be close and points to regional movements resulting in erosion and unconformity in Curaçao, to discontinuous sedimentation in Venezuela.

The unconformity at the base of the middle Curaçao formation is more difficult to trace because its age is not well known. No corresponding feature can be found in the Upper Cretaceous of western Venezuela where the sedimentation was continuous during this period (15). An unconformity exists probably in some areas of western Venezuela at the base of the Tertiary, for example, in the state of Trujillo where part of the Upper Cretaceous (the Mito Juan formation) seems to be missing. The presence of the Paleocene is known in some regions of the state of Trujillo, but in other areas of the same state it is almost certainly absent. The fossil evidence for the occurrence of lower Eocene is very scarce in western Venezuela but in wide areas of the Maracaibo basin (Colon district) sedimentation was uninterrupted from the Upper Cretaceous to the Miocene (17) while in the Trujillo foothills the lower Eocene is missing together with the Paleocene. There have thus been movements during the earlier Eocene in western Venezuela which may correspond with those preceding the deposition of the middle Curaçao formation. The possible relation between the post-middle Curaçao orogeny and the movements known to have occurred in western Venezuela during the upper Eocene have already been mentioned.

The absence of Oligocene, Miocene, and Pliocene on Curaçao is interesting because thick formations belonging to these stages are present in the state of Falcon opposite Curaçao (18). Apparently the island belonged to a positive area situated north of the deep Falcon trough unless we assume that all or part of the

Oligocene-Miocene were deposited on Curaçao but eroded prior to the Seroe Domi transgression. Several unconformities are known in the Oligocene and younger sediments in the state of Falcon. If Curaçao remained stable during that time this would be in marked contrast to the earlier geological history of Curaçao which is more accentuated by uplifts, orogenic movements, and subsidence than the history of western Venezuela. Curaçao was apparently not affected by the late Miocene-Pliocene Andean movements, and it is probable that a stable block comprising the islands Aruba, Curaçao, and Bonaire, and the peninsulas Goajira and Paraguaná on the mainland existed during the whole period (19).

The young uplifts and subsidences of Curaçao probably have their counterparts on the Venezuelan coast. The young fossil beds described by K. Martin (4) can be mentioned here but no correlation has been made.

REFERENCES


1. MOLENGRAAFF, G. J. H., "Geologie en Geohydrologie van het eiland Curaçao," *Dissertation.* Delft (1929).
2. VERMUNT, L. W. J., AND RUTTEN, M. G., "Geology of Central Curaçao," *Proc. Kon. Akad. v. Wetensch.*, Vol. 34, No. 2. Amsterdam (1931).
3. RUTTEN, L., "De geologische Geschiedenis der drie Nederlandsche Benedenwindsche eilanden," *De West Indische Gids 13*, Afl. 9 (1932).
4. MARTIN, K., "Bericht über eine Reise nach Niederländisch Westindien und darauf gegründete Studien." Leiden (1888). Geologischer Teil.
5. HUMMELINCK, P. W., "Studies on the Fauna of Curaçao, Aruba, Bonaire and the Venezuelan Islands, *Dissertation.* Utrecht (1940).
6. VAN REGTEREN-ALTENA, C. O., "Old Tertiary Mollusca from Curaçao," *Proc. Kon. Akad. v. Wetensch.*, Vol. 44, No. 10. Amsterdam (1941).
7. KOCH, R., "Tertiärer Foraminiferenkalk von der Insel Curaçao," *Eclog. Geol. Helv.*, Vol. 21, No. 1 (1928).
8. RUTTEN, L., "Tertiary Foraminifera from Curaçao," *Proc. Kon. Akad. v. Wetensch.*, Vol. 31, No. 10. Amsterdam (1928).
9. KOCH, R., Berichtigung und Ergänzung zur Notiz "Tertiärer Foraminiferenkalk etc.," *Eclog. Geol. Helv.*, Vol. 22, No. 2 (1929).
10. RUTTEN, M. G., AND VERMUNT, L. W. J., "The Seroe di Cueba Limestone from Curaçao," *Proc. Kon. Akad. v. Wetensch.*, Vol. 35, No. 2. Amsterdam (1932).
11. PIJPERS, P. J., "Geology and Paleontology of Bonaire (D. W. I)," *Dissertation.* Utrecht (1933).
12. GERTH, H., "Beiträge zur Kenntnis der mesozoischen Korallenfaunen von Südamerika," *Leidsche Geol. Meded.*, Vol. 3, No. 1 (1928).
13. MACGILLAVRY, H. J., "The Rudist Fauna of Seroe Teintje (Northern Curaçao)," *Proc. Kon. Akad. v. Wetensch.*, Vol. 35, No. 3. Amsterdam (1932).
14. SUTTON, F. A., "Geology of Maracaibo Basin, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 30, No. 10 (1946).
15. SCHAUB, H. P., "General Outline of Sedimentation in Maracaibo Basin, Venezuela," *ibid.*, Vol. 32, No. 2 (1948).
16. CUSHMAN, J. A., AND HEDBERG, H. D., "Upper Cretaceous Foraminifera from Santander del Norte, Colombia, S. A.," *Contrib. Cushman Lab. Foram. Res.*, Vol. 17, Pt. 4 (1941).
17. NOTESTEIN, F. B., HUBMAN, C. W., AND BOWLER, J. W., "Geology of the Barco Concession, Republic of Colombia, South America," *Bul. Geol. Soc. America*, Vol. 55, No. 10 (1944).
18. SENN, A., "Die stratigraphische Verbreitung der tertiären Orbitoiden mit spezieller Berücksichtigung ihres Vorkommens in Nord-Venezuela und Nord-Marokko," *Eclog. Geol. Helv.*, Vol. 28, No. 1 (1935).
19. STAFF OF CARIBBEAN PETROLEUM COMPANY, "Oil Fields of Royal Dutch-Shell Group in Western Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 32, No. 4 (1948).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1292-1330, 2 FIGS.

# DESCRIPTION, CORRELATION, AND PALEOECOLOGY OF TERTIARY CIPERO MARL FORMATION, TRINIDAD, B.W.I.[1]

R. M. STAINFORTH[2]
Bogota, Colombia

## ABSTRACT

The Cipero marl formation is defined by reference to a type section south of San Fernando, Trinidad, B.W.I. The priority of the name Cipero is indicated in a critical review of the published literature. Grounds for division into a lower (Paradise) and an upper (Cacatro) member are discussed. Criteria are listed for the recognition of three foraminiferal zones. Fossil evidence is given for believing that the period of deposition of the Cipero formation coincided fairly closely with the Oligocene epoch. The stratigraphic relations between the Cipero and other formations of the Naparima Basin are described. The probable milieu of deposition of the Cipero formation is discussed in the light of ecological evidence of its faunas and the geological history of the Naparima Basin. The conclusion is reached that the formation is an open-sea deposit of *Globigerina*-ooze type, mostly laid down at depths of 400–500 meters. In a regional sense the Cipero formation is shown to be a close equivalent in age and facies of the topmost Oceanic marls and younger marls in Barbados. Other Oligocene units described from the Antilles and Tropical America are better comparable with the Brasso and San Fernando formations of Trinidad, though correlation with the Cipero is possible on the basis of pelagic Foraminifera of limited life range.

## HISTORICAL REVIEW

The writer's purpose in defining and describing the Cipero formation is mainly objective, and the subjectivity apparent in the earlier literature is rationalized as far as possible. Intensive geological research by the Trinidad oil companies has led during the past decade to a fairly clear understanding of problems of facies, age, and structure which were insoluble before modern techniques were applied.

The formation defined in these pages has been classified under many different names, but Cipero formation is not only the name in common use but also seems to have priority over other terms. The first stratigraphic use of the name *Cipero* was made in publication by Thomas (51)[3] in 1924 in a passing reference, apparently to the whole Cipero coast sequence. Thomas was here following the manu-

[1] Manuscript received, March 25, 1948.

[2] Formerly paleontologist, Trinidad Leaseholds Ltd., Pointe-a-Pierre, Trinidad. In essentially its present form this paper was completed late in 1945, but owing to war conditions and personal factors publication has been delayed. Great thanks are due H. H. Renz for undertaking lengthy correspondence in connection with final adjustments after the writer had left Trinidad. In compiling the data specially applicable to the Cipero formation the writer has enjoyed the privilege of cooperation with many other geologists, and before proceeding with the technical part of the paper it is therefore his pleasure to make grateful acknowledgment to the following: to the Management of Trinidad Leaseholds Ltd. for permission to publish information acquired in the course of the author's work as paleontologist at Pointe-a-Pierre and to make liberal use of the company's private reports; to the past and present geologists, especially K. W. Barr, G. Frischknecht, G. E. Higgins, H. G. Kugler, R. Mühlemann, K. Rohr, and E. Strasser, of Trinidad Leaseholds Ltd., on whose field work and office compilations this paper is largely based; to H. H. Suter, chief geologist, and H. H. Renz, chief stratigrapher, for detailed criticism and discussion of the paper in its draft stage, and also to J. C. Griffiths, petrographer, for many helpful discussions on the geological history of the Naparima Basin; to S. T. Waite, chief geologist, and G. R. J. Terpstra, paleontologist, of United British Oilfields of Trinidad Ltd., with whom the zonation and nomenclature of the Cipero formation have been discussed in detail; and to A. Senn of the British Union Oil Co. of Barbados for permission to make reference to samples which he donated to the collections of Trinidad Leaseholds Ltd.

[3] Figures in parenthesis refer to the list of references at the end of the paper.

script usage of F. W. Penny. In 1935 Lehner (34) proposed to replace the colloquial name "Bamboo silt" by Cipero silt, and also mentioned the use of the name "C.S. 10 marl" (marl at Cipero Section station No. 10) for the underlying beds. Kugler (33) in 1939 extended Lehner's usage to include all the Oligocene beds at the type section in the Cipero formation. This extension was based on yet unpublished work by Renz, who in 1942 (45, pp. 547–49) indicated his recognition of a Cipero formation consisting of light-colored marls with basal and middle portions of dark-colored orbitoidal silts. The present writer follows Cushman and Stainforth (13, pp. 3, 5, 10) who in 1945 described the Cipero formation as consisting solely of the light-colored marls, the dark orbitoidal silts being transferred to the San Fernando formation.

The Cipero formation thus defined has received the following names in published literature. The subjoined notes indicate the reasons for invalidity of the earlier names.

| | | |
|---|---|---|
| 1860 | G. P. Wall and J. G. Sawkins (57, p. 37, map) | Part of the Naparima series or formation |
| 1892 | R. J. L. Guppy (24) | Part of Naparima beds |
| 1899 | J. B. Harrison and A. J. Jukes-Brown (26) | Part of Oceanic beds |
| 1907 | E. H. Cunningham-Craig (6) | Part of Naparima marls |
| 1924 | M. L. Thomas (51) | Part of Cipero Creek marls |
| 1926 | G. A. Waring (58, pp. 52–59, map) | Parts of Naparima series, including most of Princes Town marl and part of Green clay |
| 1928 | V. C. Illing (29, pp. 8, 19–24) | Part of Naparima marls, including Princes Town marl and Retrench Hill marlstone. (?) Top part in Green clay |
| 1929 | J. A. Cushman and | Green clay, Lower marl, and Upper marl |
| 1934 | P. W. Jarvis (9, pp. 10, 12, 14, 17: 10, p. 73) | |
| 1935 | E. Lehner (34) | Included Princes Town marl and Alley Creek beds, both defined as part of Green clay |
| 1936 | H. G. Kugler (33) | Cipero formation (*pars*) including Freeman's Bay beds |
| 1942 | H. H. Renz (45, pp. 547–49) | Lower part and upper member of Cipero formation |
| 1945 | J. A. Cushman and R. M. Stainforth (13) | Cipero formation |

NOTES ON FOREGOING LIST OF NAMES

1. The term *Naparima* is retained for the group inclusive of all the basinal marls, that is, the Lizard Springs, Navet, Hospital Hill, and Cipero formations and other minor units.
2. The term *Oceanic* is not acceptable in modern terminology. It was used in Trinidad as an extrapolation from the Barbados sections.
3. Apart from its unsuitability in modern nomenclature the term *Green clay* was an unstable one used in different senses by different authors.
4. The Princes Town marl as a lithologic unit was never clearly distinguished from the Lower Green clay. Waring (58, p. 54) did mention a type locality (Princes Town railway station) for his Upper Princes Town marl, but the relationships of his Upper and Lower Princes Town marl and Lower Green clay to one another are obscure, and even more so to the units of other authors. Later a distinction was made on biostratigraphic grounds (presence or absence of *Globorotalia fohsi et cetera*) following unpublished work by P. W. Jarvis, but this should have automatically rendered the application of a place-name invalid. However, the name Princes Town marl is retained in colloquial usage for Zone II of Cushman and Stainforth.
5. The name Retrench beds is still valid for siliceous (radiolarian) marls in the upper part of the Cipero formation. S. T. Waite (private communication) has recommended a broader usage of the term, but his definition of it would be sub-zonal, based on the life-range of *Globigerinatella insueta*, and a topographic name would therefore be incorrect.

6. The terms Lower, Middle, and Upper marl are too vague for modern terminology.
7. The marls at Alley Creek are identical with beds exposed along the Cipero type section and the name Cipero (Thomas 1924 after Penny, *ms.*) therefore has priority over Alley's Creek (Liddle 1928). The title Alley Creek shell bed is valid for the fossiliferous layer exposed on the beach there.
8. The term Godineau River marls is synonymous with Illing's Retrench marlstone and is therefore redundant.
9. The name Morne Diablo *formation* is misleading, as Kugler's intention was evidently the erection of a local *stage*. The suggestion did not pass into general usage and the name Morne Diablo is only applied to the local development of limestone within the Ste. Croix beds.
10. For many years the orbitoidal "silts" of Mount Moriah and Point Bontour were considered to be exclusively Eocene and the overlying marls Oligocene. This led to a convenient (though taxonomically incorrect) definition of two formations on an age basis, one Oligocene and one Eocene. The utility of this classification was destroyed by the discovery that the "silts" included lower Oligocene beds. This fact had not been fully assimilated in 1942 and Renz (45, p. 547) therefore published the nomenclature then in use by Trinidad Leaseholds Ltd. On lithological grounds the present author has no hesitation in transferring the "silty" base of Renz' Cipero formation to the San Fernando formation. On the same grounds the "middle part of the formation" of Renz is likewise transferred, but there is a degree of uncertainty in this case because of its structural isolation.

## TYPE LOCALITY

### GEOGRAPHIC AND STRUCTURAL SETTING

The type section of the Cipero formation is situated immediately south of San Fernando and is defined as the low stretch of cliffs extending southwest from the southern end of the sea-wall almost to the mouth of the Cipero River. These cliffs afford a permanent natural section of the low rolling terrane typical of the Naparima region of Trinidad. The Tertiary marls of this area are uniform readily weathered deposits without any conspicuous hard beds. The name Naparima is an apt Carib word said to mean "no water," for despite heavy seasonal rainfall there are scarcely any permanent streams in the region. A topography of low relief has developed with no natural outcrops and access is impeded by intensive cultivation of sugar and other crops. Because of these factors the coast section becomes an obvious choice as type locality.

The Cipero coast section falls structurally near the northwest corner of the Naparima Basin in what might be called the San Fernando structural complex. The main structural feature of San Fernando is an anticlinal fold, apparently produced by puckering of a block of sediments moving southwestward along a line running past the southeast end of Naparima Hill to the Cipero River mouth. Naparima Hill, formed of resistant Upper Cretaceous argiline, is the surface core of the main fold. The Cipero section falls within the southern flank of the fold and is therefore part of the block of sediments which acted as a buttress to lateral movement. Much of the tectonic stress was dissipated in creating the complex adjustment structure of Hospital Hill with its buckling and possible overthrusting of incompetent beds, but even so the Cipero section displays imbrication and a form of closely spaced *échelon* thrusting as evidence of the intense compaction it has undergone.

Such features are undesirable in a type section, but outcrops in Trinidad of all beds below the Miocene are practically confined to the same ancient structural

axes as were again activated in the final orogeny responsible for the present-day structural form of the island. Consequently, no undisturbed sections of any Oligocene beds are to be expected at surface, although they may exist at inaccessible depths in structural depressions. The type section nominated for the Cipero formation is unrivalled for completeness and accessibility. The accompanying map and section (Fig. 1) show structural and topographic details of the Cipero section.

## LITHOSTRATIGRAPHY

### GENERAL

The Cipero formation belongs to the Naparima marl group of southern Trinidad, which consists of highly calcareous argillaceous sediments, typically white or light-colored in exposures. The term marl is applied in Trinidad to rather granular clays which react violently with dilute acid, as distinct from unctuous calcareous clays which give a milder surface effervescence. The older marls of the group occur at surface in disconnected outcrops, mainly in anticlinal cores. They are white, massive, in places chalky, and for the most part are classed together as the Navet formation of lower to middle Eocene age. The Lizard Springs (Upper Cretaceous-Paleocene) and Hospital Hill (upper Eocene) formations also fall in the lower part of the group, but their status as purely lithologic units is questionable.

The younger marls of the group are of a distinct greenish or bluish gray tinge, less indurated and more definitely argillaceous than the Navet marls. Freshly broken samples show abundant whitish Foraminifera in a grayish matrix. These upper marls of the Naparima group form the Cipero formation.

The formation is not well bedded but is jointed parallel with the bedding into irregular masses of flattened elliptical cross section. When a sufficiently large section is exposed, as on the coast or in road cuts, the dip is given by the trend of this jointing. Vertical jointing is irregular and gives rise to the cuboidal fracture which is a typical feature of the formation. According to J. C. Griffiths and H. H. Renz (private reports) the carbonate ion content of the Cipero marls, as measured with a Schrötter apparatus, varies directly with the foraminiferal content and when expressed as calcium carbonate may reach 60 per cent by weight, with an average value of 32 per cent (for details see "Conditions of Deposition"). The thickness of the Cipero formation can not be precisely stated. Because of structural complexity at the type section, including imbrication and internal thrusting, measurements made there are unreliable. Well evidence is not complete enough even for a figure based on piecemeal evidence. The apparent thickness at the type section is of the order of 2,300 feet, exclusive of the Flat Rock tongue, the imbricated Hospital Hill marl and an unknown but probably small part at the top of the formation. Further characteristics of the formation are mentioned in the following traverse of the type section.

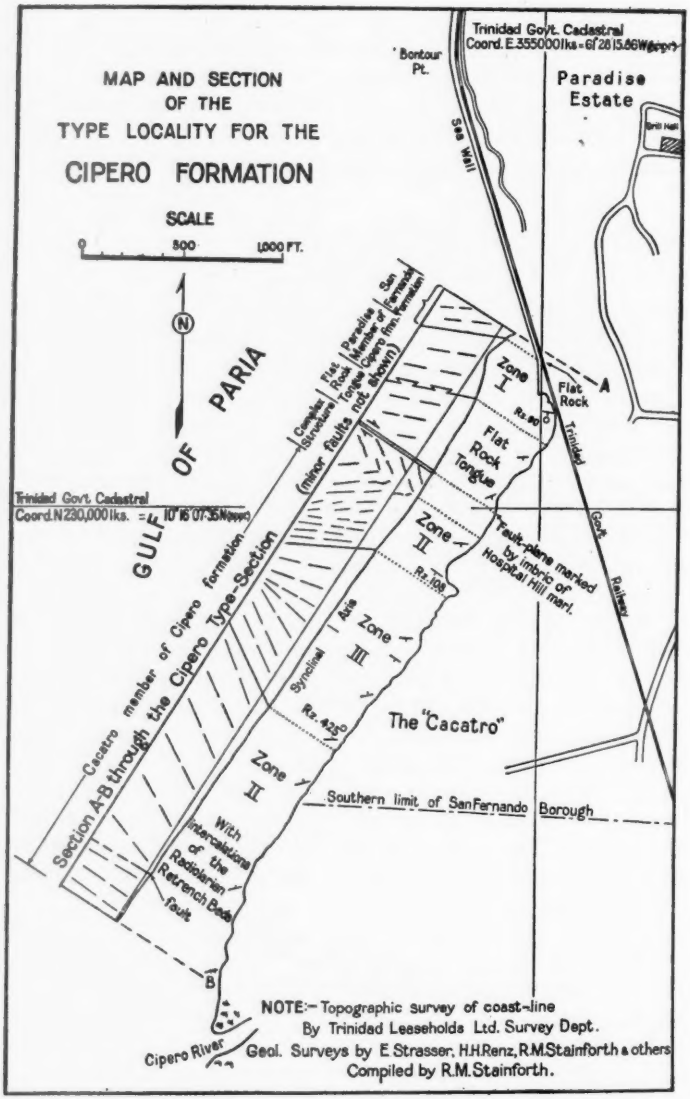



FIG. 1.—Map and section of type locality of Cipero formation. Page must be turned to obtain natural perspective of section.

### TRAVERSE OF TYPE SECTION

The Cipero section is best studied at low tide during the dry season (January to March). In the wet season there are extensive landslips, accompanied by flows of semi-fluid mud, which obscure the outcrops at the base of the cliffs. At low tide the inter-tidal flats show the general attitude and fault pattern of the marls. Faulting is in the form of an *échelon* of closely spaced (3–10 feet) thrusts at an angle slightly oblique to the bedding. It is not possible to gauge the exact effect of this thrusting, but probably the apparent thickness is greater than the true thickness of each unit affected.

Starting at the southern end of the sea-wall the section runs almost straight for 2,700 feet in the direction S. 35° W., except for the Cipero Nose, a blunt but conspicuous spur of massive marl centered at 900–1,000 feet from the end of the sea-wall. In the southern part near the point indicated there is a marked swing eastward, so that the last 800 feet of exposures trend S. 15° W. Swampy land bordering the Cipero River mouth marks the southern end of the type section.

In the following table distances are given as if measured southward at beach-level along the two straight lines indicated as marking the topographic outline of the section, except that the Paradise-Flat Rock contact (260 feet) is measured in a straight line from the end of the sea-wall.

### CONTACTS

The basal contact of the formation is not exposed at the type section but somewhat farther north, at Point Bontour, the Cipero marls overlie beds of the San Fernando formation, of which the topmost part has weathered to the appearance of a massive indurated marl, highly limonitic and gypsiferous, with numerous layers crowded with orbitoids. Slight lenticularity and intercalation indicate that the contact is transitional. The contrast between the orbitoidal San Fernando formation and the light-colored Cipero marl is unmistakeable. Furthermore the San Fernando beds are more resistant to erosion and on the south side of Point Bontour form a small spur, of which the south face marks the San Fernando-Cipero contact.

Basinward the Cipero formation rests on homologous marls of upper Eocene age, known as the Hospital Hill marl. In clean exposures the Hospital Hill marl can be differentiated by its creamy white to ash-gray color and by its nodular habit, though in normal mapping of the Cipero-Hospital Hill contact reliance is placed on foraminiferal zonation rather than on lithological differences.

The top of the Cipero formation is not preserved at the type section but the highest beds present are identical with those underlying the Lengua calcareous clay at inland sections. Along the Princes Town-Oropouche Lagoon trend numerous anticlines expose the sequence Cipero marl—Lengua calcareous clay—Cruse non-calcareous clay. The Lengua beds in general are less calcareous and more plastic than the Cipero marls, and are ordinarily darker in color such as olive-green or dark blue-gray. The presence of marcasite or pyrite is typical of un-

| *Distance in Feet* | *Lithology* | *Direction of Dip* | *Angle of Dip* | *Comments* |
|---|---|---|---|---|
| 0–260 | Light greenish gray foraminiferal marl, massive when wet, tending to cleave into irregular rhombs when dry | N. 175–180° E. | 70–80° | Paradise member |
| 260–825 | Black and gray-black foraminiferal marl and marly clay, the dry fracture typically suggesting silty texture. Characterized by fetid odor when freshly broken. At southern end nests of orbitoids common, also megafossils, well preserved but difficult to extract. Interbedded lenses of light-colored marl occur sparsely | N. 145–190° E. | 60–80° | Flat Rock tongue ("Bamboo clay" *auct.*)<br>Light-colored marl contains Zone I faunas |
| 825–845 | White marl | Dip not apparent | | Tectonic wedge of Hospital Hill marl |
| 845–900 | Imbricated and slickensided light gray-green marl with streaks of gray-black marl | Contorted | | Microfaunas show Zone III marls in presumed faulted contact with the Hospital Hill marl, and Zone II marls on the South. Dark marls are of Flat Rock type and have been regarded as signs of upward transition from Flat Rock tongue to Cacatro member |
| 900–1,000 | Massive dark gray marl, silver-gray on sun-dried surfaces | N. 180–220° E. | 60–70° | Cipero Nose, formed of lower Cacatro marls |
| 1,000–1,050 | Marl-breccia consisting of angular pieces of greenish marl, mostly polished or slickensided, in matrix of same material | Unbedded | | *Cf.* Illing's "Green Clay Breccia" (29, pp. 24–26), commonly obscured by landslips |
| 1,050–2,000 | Gray-green marl with conspicuous orange mottling due to films of iron oxide on fracture planes | In northern half N. 180–210° E.<br>In southern half N. 5°E.–20° W. | 70–80°<br>70–80° | Upper Cacatro marls, so-called "Golconda" |
| 2,000–3,500 | Massive gray-green marl as at Cipero Nose, in places merging into layers of harder creamy gray indurated marl or chalky marlstone. At 3,200 feet, 1-foot vein of manjak commonly visible | N. 0–20° W. | 60–90° | Lower Cacatro marls with some intercalations of Retrench siliceous marls |

weathered Lengua, which consequently develops rich orange-brown staining on weathering, whereas the Cipero tends to remain light-colored, commonly light fawn or khaki.

DIVISION INTO MEMBERS

Recent authors have regarded the Flat Rock tongue as an intercalation separating an upper and a lower member of the Cipero formation. Renz expresses this view clearly (45, p. 547) and it is applied in age-assessment by Cushman and Stainforth (13, pp. 7–12). The present author maintains this attitude, but the evidence is not entirely conclusive and the possibility is open that the Flat Rock "tongue" is rather an upfaulted block of the youngest part of the San Fernando formation.

As the assumed lower contact of the Flat Rock tongue (at 260 feet on the type-section traverse) is affected by the fault pattern, it can not be dogmatically stated that the Flat Rock tongue overlies the lower Cipero marls at this point, though there is no imbrication or other evidence of large displacement. At the southern extremity of its outcrop (at 825 feet on the type-section traverse) the Flat Rock tongue abuts against the most complex minor structure in the section. At this point, as first demonstrated by S. T. Waite and G. R. J. Terpstra (private communication), the Flat Rock tongue is in direct contact with a thin band of upper Eocene Hospital Hill marl, which in turn is in contact to the south with light-colored Cipero marl. The structural complexity is further obscured by landslips and can not be resolved without recourse to paleontology.

A detailed paleontological discussion follows later in this paper and the pertinent conclusions need only be summarized here. On the evidence of its mollusk fauna the Flat Rock tongue has been placed in the middle Oligocene by R. Rutsch (45, pp. 547, 548). The larger Foraminifera of the Flat Rock tongue and of the basal Oligocene San Fernando formation are very similar, but C.M.B. Caudri noted differences on which she claimed middle Oligocene age for the first-named (13, p. 11). The absence of *Miogypsinas* and the presence of *Globigerina* cf. *concinna* favor an age determination not younger than the early part of the middle Oligocene. The genus *Halkyardia* appears in the basal Oligocene but has not been seen in the Flat Rock tongue faunas.

On this evidence the Flat Rock tongue is apparently younger than the basal Oligocene at Point Bontour, and is therefore either synchronous with or younger than the lower Cipero marls. The evidence available does not suffice to prove one or other of these alternatives. However, the presence of streaks of dark marl in the base of the upper Cipero marls (845–900 feet on the type-section traverse) suggests a direct upward transition from the Flat Rock tongue. The facies type of the lower Cipero marl suggests that it underlay the Flat Rock tongue rather than that it was a localized lateral equivalent.

Regarding structure, if the Flat Rock tongue is younger than the basal Oligocene at Point Bontour, then its relationship to the band of Hospital Hill marl at the type section is discordant. The present writer takes the view that this is a tectonic wedge of Eocene marl, in effect the sole of a thrust plane. There is a comparable case at the cliff-top near the Naparima Club, between the type section and Point Bontour, where an imbric of Navet marl separates adjacent

exposures of Cipero marl. In the example at the type section the Flat Rock tongue appears to have over-ridden the younger Cipero marls, the thrust pressure causing an anticlinal fold to the south. Such a structure is congruous with the general structural picture of the San Fernando area.

Pending more satisfactory evidence, such as might be forthcoming from wells drilled south of San Fernando, the Flat Rock tongue is regarded as an intercalation between the higher and lower marls of the Cipero formation. The two members into which the Cipero is thus divided have never been formally named on purely lithological grounds. It is here proposed to name the lower one the Paradise member, from Paradise estate situated just north of the type section. For the upper one the term Cacatro member is offered, this name being current Creole patois for the area around a one-time refuse dump in the southern part of the type section. The synonymy and status of these two members are discussed in subsequent paragraphs. It must be emphasized that separation of the two members is based solely on the presumed existence of the Flat Rock tongue between them, and not on their lithological differences, which are considered too slight for such a purpose. It is probable that in much of the Naparima Basin the Flat Rock tongue is absent (having passed laterally into marls) and in such places lithological subdivision of the Cipero formation is impracticable.

PARADISE MEMBER

Synonymy:

| | | |
|---|---|---|
| 1929 | J. A. Cushman and P. W. Jarvis (9, p. 12) | Lower marl |
| 1930 | J. A. Cushman and Y. Ozawa (11, p. 39) | Lower marl |
| 1935 | E. Lehner (34) | In a footnote: "Ces marnes sont designées par micropaléontologistes locaux sous le terme de C.S. 10 marl." C.S. 10 stood for Cipero Station No. 10. Lehner also mentioned the term Lower marl, but regarded it as inadequately defined |
| 1936 | J. A. Cushman and F. L. Parker (12, p. 39) | "Lower marl" |
| 1942 | H. H. Renz (45, p. 547) | Unnamed marl between basal and middle parts of Cipero formation |
| 1945 | J. A. Cushman and R. M. Stainforth (13, p. 4) | Marl equivalent to their Zone I (*Globigerina concinna* zone) of Cipero formation |

Prior to the systematic application of micropaleontology the Paradise member was not separated from the more extensive Cacatro member, the San Fernando "silts" at Point Bontour being, it is now thought, erroneously identified with the Flat Rock tongue as a single bed underlying both the Paradise and Cacatro members in a sigmoid fold. In 1942 Renz indicated the distinction between the two marl members but gave no name to the Paradise member.

The base of this member is also the base of the formation and, as already mentioned, it is in transitional contact with the underlying San Fernando formation. The top is believed marked by a change, also transitional, from light-colored marl to the blackish sediments of the isolated Flat Rock tongue. Because of the limited basinward extent of the San Fernando formation (including the

Flat Rock tongue), the Paradise member has not been widely recognized. One definite occurrence is known north of San Fernando near the mouth of the Vista Bella River, where the contact between the San Fernando and Cipero formations is exposed in a railway cut and it was also encountered in shallow structure drilling. South of San Fernando, though the higher Cacatro member is commonly exposed in anticlinal cores, beds as low in the succession as the Paradise member are rarely exposed. Near Dunmore Hill, where Eocene marls crop out, absence of the San Fernando formation and discordance of structure make it impossible to recognize the Paradise member as a lithological unit. Despite the paucity of known developments of this member at surface there is little doubt that it is an extensive unit of which we may learn more if future oil exploration results in deep tests of the Naparima Basin. Its thickness at the type section is approximately 350 feet.

CACATRO MEMBER[4]

Synonymy: Prior to 1926 the Naparima marl was scarcely subdivided, but after that date several partly synonymous terms were applied to the Cacatro member.

| | | |
|---|---|---|
| 1890<br>1893 | R. J. L. Guppy (23, 25) | *Polycistina* beds, radiolarian marls of S. Naparima (Retrench beds of current usage) |
| 1926 | G. A. Waring (58, pp. 54, 57–59) | Upper Princes Town marl and (?) part of Green clay |
| 1928 | V. C. Illing (29, pp. 20–24) | Princes Town marl and radiolarian Retrench Hill marlstone. Also (?) part of Green clay |
| 1928 | R. A. Liddle (35) | Alley's Creek beds and Godineau River marls |
| 1929<br>1934 | J. A. Cushman and P. W. Jarvis (9, pp. 10, 14, 17; 10, p. 73) | Upper marl and Green clay |
| 1935 | E. Lehner (34) | Princes Town marls and Alley Creek beds, both classed as part of Green clay. Terms Upper marl and Radiolarian marl mentioned but regarded as inadequately defined |
| 1936 | H. G. Kugler (31) | Lower Green clay, Alley Creek beds, and Princes Town marls |
| 1942 | H. H. Renz (45, pp. 549) | Upper member of Cipero formation |
| 1945 | J. A. Cushman and R. M. Stainforth (13, p. 4) | Marls equivalent to Zones II (*Globigerinatella insueta* zone) and III (*Globorotalia fohsi* zone) of Cipero formation |
| Current colloquial usage | | Princes Town marl (for lower part) and Golconda marl (for upper part) |

The nomenclature of this member was confused by the use of place names for biostratigraphic units. In broad terms the Princes Town marl was the lower and the Lower Green clay the upper of the two foraminiferal zones jointly equivalent to this member. No corresponding lithological subdivision is now recognized, as indicated by the simplified usage introduced by Renz. The name Cacatro is proposed as having a more precise significance than his term "upper."

The terms Princes Town marl and Golconda marl should be used only in an informal colloquial sense as they are foraminiferal zones, that is, biostratigraphic units which should not be designated by place names in formal usage. It must be recognized that within oil companies, where discussions between geologists and

[4] Pronounced Ká-ká-trōh.

laymen are a constant necessity, such informal terms possess a certain value, provided their limitations are realized.

At the type section the base of the Cacatro member is not clearly defined owing to a structural complexity but there is some evidence of transitional contact with the top of the Flat Rock tongue. The top of the member coincides with the top of the formation as already described. The Cacatro member is developed throughout the Naparima Basin, as is known from numerous anticlinal cores and from well evidence. It is by far the best known unit in the whole Naparima group and for the most part is lithologically uniform, a light greenish gray or fawn marl as at the type section. Beds laid down under shallower-water conditions occur as lenses of various sizes and are classed together as the Ste. Croix beds. Here and there, layers, rather harder than the rest of the member, are rich in Radiolaria. Known as the Retrench beds, these occur in the southern part of the type section and are well developed at Hermitage and Retrench estates to the south of San Fernando. At Freeman's Bay near Otaheite strings of asphalt-impregnated mudstone concretions are interbedded with marls of the Cacatro member. These are of interest as they contain a deep-water mollusk fauna. Similar gray to brown concretions washed from the cliffs are conspicuous on the foreshore at the Cipero type section but are rarely fossiliferous. Illing (29, p. 24–26) described as Green Clay Breccia a bed consisting of angular pieces of marl in a marl matrix, and traced it for 13 miles inland. A similar bed occurs at the type section and seems to be an intraformational breccia within the Cacatro member as no difference in composition has been detected between matrix and components. The mechanics by which such beds were formed are not clear, though submarine slumping has been suggested. Veins of manjak, such as one which has been exposed at 3,200 feet on the type section traverse for several years, seem to have no genetic relation to the Cipero formation. They occur in the San Fernando area in rocks of different ages and facies. The Cacatro member at the type section has an incomplete apparent thickness of 2,000 feet, but this figure may be exaggerated because of internal thrusting.

## BIOSTRATIGRAPHY

### ZONATION

Megafossils are so scarce in the Cipero formation that they play a negligible part in zonation, which is almost entirely based on differences in the rich foraminiferal faunas at different levels in the marls. Three foraminiferal zones zones are readily recognizable, as stated by Cushman and Stainforth (13). As defined herein their status is the same as Rowe's zones of the English chalk, namely, paleontologically defined subdivisions of one uniform, lithologically defined formation. It is known, however, that *Globorotalia fohsi* is a time-marker for the upper Oligocene of the Caribbean area, not only in the deeper-water marls of Trinidad and Barbados, but also in such sublittoral beds as the Brasso formation of Trinidad, Cojimar formation of Cuba (42), Agua Salada group of Venezuela (H. H.

Renz, private communication). Similarly *Globigerina* cf. *concinna* occurs in the early Oligocene part of the San Fernando formation of Trinidad, including the Flat Rock tongue, the lower Oligocene Alazan formation of Mexico (41), the Oligocene Carapita formation of Venezuela (15), the lower and early middle Oligocene of Ecuador and the lower Oligocene part of the Oceanic formation of Barbados (hitherto unpublished record). From this evidence it is clear that we are dealing with biostratigraphic units of regional significance. For such units the stratigraphic term "zone" is the correct title.

Cushman and Stainforth (13, p. 4) designated the following type samples for the three zones.

Zone I (*Globigerina concinna* zone)

Sample Rz. 90, Trinidad Leaseholds Ltd. Catalogue No. 21721.
Trinidad Government Cadastral Co-ordinates: N.230,620 links
E.354.950 links

Situated in base of cliffs, 375 feet southward from 35½ mile-post on railway, stratigraphically 80 feet below Paradise-Flat Rock contact

Zone II (*Globigerinatella insueta* zone)

Sample Rz. 108, Trinidad Leaseholds Ltd. Catalogue No. 21743.
Trinidad Government Cadastral Co-ordinates: N.229,450 links
E.354.250 links

Situated on Cipero Nose

Zone III (*Globorotalia fohsi* zone)

Sample Rz. 425, Trinidad Leaseholds Ltd. Catalogue No. 61418.
Trinidad Government Cadastral Co-ordinates: N.228,300 links
E.353,600 links

Situated in base of cliff in southern (north-dipping) limb of syncline at Cipero type section, 120 feet northeast from boundary between middle and upper zones, 880 feet in straight line southwest from Rz. 108.

The following table shows the physical relationship between the lithostratigraphic and biostratigraphic subdivisions of the Cipero and associated formations.

| *Lithological Units* | | *Biostratigraphic Units* |
|---|---|---|
| Lengua clacareous clay member of Cruse clay formation | | *Globorotalia menardii* zone |
| Cacatro marl member of Cipero marl formation | | *Globorotalia fohsi* zone |
| | | *Globigerinatella insueta* zone |
| (?) Flat Rock tongue of San Fernando formation | | *Globigerina concinna* zone |
| Paradise marl member of Cipero marl formation | | |
| Variegated beds of San Fernando formation | Hospital Hill marl formation | *Hantkenina alabamensis* zone |

NOTES ON ZONAL ASSEMBLAGES

There is a great difference between the faunas of Zone II of the Cipero formation and the *Hantkenina alabamensis* zone of the Eocene Hospital Hill marl, but the intervening Zone I of the Cipero contains a transitional fauna with some spe-

cies surviving from the upper Eocene and others which, although not attaining their acme below Zone II, had already made sporadic appearances. Thus Zone I is characterized as much by the co-existence of these two faunal elements as by the presence of markers restricted to this zone. Among these latter *Globigerina* cf. *concinna* is the most useful as it commonly occurs in floods, is not known from older or younger zones, and can not be confused with any other species known from the Naparima marls. *Globigerina dissimilis* is also known from the upper Eocene and the late middle Oligocene of Trinidad, but it most conspicuous in the Zone I faunas. The full list of species regarded as time-markers virtually restricted to Zone I is as follows.

*Buliminella grata** Parker and Bermudez
*Cassidulinoides bradyi* (Norman)
*Discorbis ciperensis* Cushman and Stainforth
*Entosolenia flintiana* (Cushman) var. *plicatura* Cushman and Stainforth
*Entosolenia laevigata* (Reuss)
*Entosolenia orbignyana* (Sequenza) var. *clathrata* (Brady)
*Globigerina* cf. *concinna* Reuss
*Hormosina glabra* Cushman and Stainforth
*Hyperammina elongata* Brady
*Lagena ciperensis* Cushman and Stainforth
*Lagena* cf. *laevis* (Montagu)
*Lagena semicostata* Stoltz
*Lagena tetragona* Parker and Jones
*Nodosarella reflecta* Cushman and Stainforth
*Nodosarella salmojraghi* Martinotti
*Pyrulina cylindroides* (Roemer) var. *curvatura* Cushman and Stainforth
*Rectogümbelina inopinata* Cushman and Stainforth
*Schenckiella petrosa* (Cushman and Bermudez)
*Uvigerina capayana* Hedberg
*Uvigerina spinicostata* Cushman and Jarvis
*Vulvulina jarvisi* Cushman

* The variety *B. grata* var. *spinea* Parker and Bermudez has also been recorded in Zone I but is extremely scarce.

For reasons discussed later, the age of Zone I is taken as essentially lower Oligocene but possibly inclusive of topmost Eocene and basal middle Oliogocene.

Treated jointly Zones II and III of the Cipero contain many Foraminifera which are absent in Zone I and the older Naparima marls. A selected list of these species follows.

*Anomalina subbadensis* Pijpers
*Bulimina alazanensis* Cushman
*Bulimina tuxpamensis* Cole
*Cassidulina spinifera* Cushman and Jarvis
*Ellipsonodosaria annulifera* Cushman and Bermudez
*Ellipsonodosaria mappa* Cushman and Jarvis
*Ellipsonodosaria verneuili* (d'Orbidny) var. *paucistriata* (Galloway and Morrey)
*Entosolenia flintiana* (Cushman)
*Entosolenia longispina* (Brady)
*Entosolenia spinolaminata* Cushman and Stainforth
*Gaudryina flintii* Cushman
*Globigerinatella insueta* Cushman and Stainforth
*Globigerinoides conglobata* (Brady)
*Globigerinoides rubra* (d'Orbigny)
*Globigerinoides sacculifera* (Brady)
*Globorotalia canariensis* (d'Orbigny) (small form)
*Globorotalia praemenardii* Cushman and Stainforth
*Guttulina byramensis* (Cushman)

*Guttulina jarvisi* Cushman and Ozawa
*Gyroidina altispira* Cushman and Stainforth
*Lagena crenata* Parker and Jones var. *capistrata* Cushman and Stainforth
*Lagena* cf. *lagenoides* (Williamson)
*Lagena nuttalli* Galloway and Heminway
*Lagena pulcherrima* Cushman and Jarvis
*Lagena waringi* Cushman and Stainforth
*Nodosaria stainforthi* Cushman and Renz
*Planulina marialana* Hadley
*Planulina* cf. *wuellerstorfi* (Schwager)
*Plectofrondicularia mexicana* (Cushman)
*Plectofrondicularia morreyae* Cushman
*Plectofrondicularia spinifera* Cushman and Jarvis
*Pleurostomella cubensis* Cushman and Bermudez
*Prygo murrhina* (Schwager)
*Robulus clericii* (Fornasini)
*Saracenaria* cf. *acutauricularis* (Fichtel and Moll)
*Schenckiella suteri* Cushman and Stainforth
*Sigmoilina schlumbergeri* Silvestri
*Sigmomorphina trinitatensis* Cushman and Ozawa
*Siphogenerina basispinata* Cushman and Jarvis
*Siphogenerina multicostata* Cushman and Jarvis
*Siphogenerina seriata* (Cushman and Jarvis)
*Textularia leuzingeri* Cushman and Renz
*Trifarina bradyi* Cushman
*Uvigerina auberiana* d'Orbigny var. *attenuata* Cushman and Renz
*Uvigerina rustica* Cushman and Edwards
*Vulvulina guppyi* Cushman and Stainforth

Zones II and III are differentiated from one another mainly by the presence, commonly in abundance, of *Globorotalia fohsi* in the upper, Zone III, which is defined by the life-range of this species. The large form of *Globorotalia canariensis* is almost as good a marker for Zone III, although the smaller form is also known from Zone II and from the Lengua beds (*Globorotalia menardii* zone). Also of use in differentiating the faunas of Zone III is the presence in them of the following.

*Bulimina* (*Desinobulimina*) *illingi* Cushman and Stainforth
*Globigerina* cf. *digitata* Brady (large bizarre form)
*Pseudoglandulina gallowayi* Cushman

The assemblage of Zone II is diagnosed as much by the absence of the *Globorotalias* of Zone III as by the presence of any distinctive species restricted to this interval. The name-fossil for the zone, *Globigerinatella insueta*, is more common there than in Zone III, but has been recorded in the latter. The interval between the highest occurrence of *Globigerina* cf. *concinna* and the lowest record of *Globigerinatella insueta* is currently included in Zone II, though as G. J. R. Terpstra has pointed out (private communication) the absence of these two species and the presence of *Globigerina dissimilis* could be taken as criteria valid for the erection of an additional zone. The following five species have not as yet been recorded in Cipero marls other than those of Zone II, but they are all scarce and their value in zonation should not be overrated.

*Bulimina bleeckeri* Hedberg
*Plectofrondicularia nuttalli* Cushman and Stainforth
*Pleurostomella* cf. *acuta* Hantken

*Uvigerina gallowayi* Cushman
*Virgulina ciperana* Cushman and Stainforth

Where known at present the Radiolarian Retrench beds occur in the top part of Zone II and in a local sense they are of zonal value on this account. They have not been given a formal place in the zonation of the Cipero formation because our knowledge of them is scanty.

The lithological boundary between Cipero marls and the overlying Lengua calcareous clays is almost coincident with the disappearance of *Globorotalia fohsi* from the faunas and the appearance in its place of *G. menardii*. There is only negligible overlap in range of these two species, but *G. praemenardii*, a primitive form less robust than the true *G. menardii*, occurs in Zones II and III of the Cipero as well as in the Lengua.

The joint age of Zones II and III, as discussed further in a subsequent section, is taken as inclusive of late middle Oligocene and upper Oligocene in the Antillean usage of these terms, though Zone III may include part of the European lower Miocene, if the Aquitanian is placed in the lower Miocene.

## NON-CHRONOLOGIC BIOSTRATIGRAPHY

In recent years there has been a welcome tendency in American geological literature toward more careful choice and use of stratigraphic terms. In particular, discrimination has been required between rock, time and time-rock units, typified respectively by formations, periods, and stages. The desirability of adherence to uniform rules of nomenclature is almost self-evident, but has been ably expounded by Schenck, Muller, Hedberg, and others (17). Nevertheless, it seems to the writer that in the swing from unstabilized to precise terminology a valuable stratigraphic tool has been either lost sight of or tacitly condemned on false grounds. The point at issue is the use of fossils, in the present instance Foraminifera, in identifying formations and other lithological units. As long ago as 1923 T. W. Vaughan (54) published the following remarks.

> It may be possible to use smaller foraminifera in another way than as indicators of paleontologic zones of definite age—this is as constituents of sediments . . . . It is well known that the recognition of such peculiarities of sediments as the presence of phosphatic granules, glauconitic grains, and mica flakes assist in the identification of beds . . . . If a bed is known to contain a certain type of foraminiferal fauna it is reasonable to expect that such a bed may be identified by means of its foraminiferal fauna.

The Foraminifera in any sample of a formation fall into three main categories, namely, time-markers, facies-markers, and a residuum of stratigraphically useless species. In oil-field stratigraphy the time-markers, that is, species of proved short vertical ranges, are the best known and most discussed species, because in subsurface correlations their vertical distribution is the basis on which all time-stratigraphic units are erected. The Foraminifera listed in the preceding paragraphs as useful in zonation comprise the time-markers of the Cipero formation. Stratigraphically useless species include ubiquitous forms and very scarce species only

known from sporadic records. There remain the facies-markers, species which have a long vertical range but are restricted in the lateral sense to rocks indicative of a definite facies of deposition. Rocks indicative of a definite facies commonly have uniform lithologic features and are thus definable as a group, formation, member or bed according to the magnitude of their expression. The facies-markers as here defined are as much a criterion for the recognition of this unit as are the customary factors of rock-type, grain-size, bedding, *et cetera*. Provided the difference between time-markers and facies-markers be clearly maintained, the latter can be very useful in formation mapping.

The Tertiary formations of the Naparima Basin consist predominantly of marls and calcareous and non-calcareous clays, incompetent beds which have suffered strong tectonic deformation. The river drainage system is mostly dendritic and topography shows little relation to geologic structure. Natural outcrops are rare and commonly rendered useless by the deep surface weathering which, coupled with a covering of tropical vegetation, makes surface geologic mapping difficult. Most of the oil companies rely for their information on hand-auger surveys supplemented as necessary by test pits. K. Rohr (46) has recently introduced a core-auger with which small, undistorted, orientated formation samples are obtained, a vast improvement on the spiral cuttings obtained with the normal type of auger. With this improved technique a purely lithological map can be made of a high degree of accuracy. The possibility remains, however, that Cipero marls may occasionally be confused with highly calcareous clays of the Esmeralda, Ste. Croix, or Lengua: or non-calcareous clays of the Cruse, Nariva, and Ste. Croix may be mis-identified. Such points are readily settled by reference to the facies-markers among the Foraminifera of the doubtful samples.

Perhaps the most useful function of facies-markers is their use in recognition of lateral intermingling of adjacent facies. The transitional boundaries between a lens of Ste. Croix calcareous clay in Cipero marl, or between the latter and the Esmeralda calcareous clay, are far from readily apparent in the field, but can be demonstrated with precision by the use of facies-marker Foraminifera. The fullest value of this approach becomes evident when the stage of paleogeographic restorations has been reached.

Facies-markers of the Cipero formation, benthonic species which occur in all three zones but in Trinidad are virtually absent in their lateral equivalents in different facies include the following. A significant proportion of them have only been recorded in the Naparima marls of Trinidad and homologous marls in Cuba, and they are not recorded from neighboring countries where the mid-Tertiary seas were shallower.

*Ammolagena clavata* (Parker and Jones)
*Ammovertella* spp.
*Bolivina tectiformis* Cushman
*Bolivinopsis cubensis* (Cushman and Bermudez)
*Bulimina jarvisi* Cushman and Parker
*Cibicides* cf. *atratiensis* Tolmachoff
*Cibicides cicatricosa* (Schwager)

*Dentalina havanensis* Cushman and Bermudez
*Dentalina semilaevis* Hantken
*Dorothia brevis* Cushman and Stainforth
*Ellipsoglandulina exponens* (Brady)
*Ellipsoglandulina robustior* Cushman and Stainforth
*Ellipsolagena barri* Cushman and Stainforth
*Ellipsonodosaria decurta* Bermudez
*Ellipsonodosaria nuttalli* var. *gracillima* Cushman and Jarvis
*Ellipsonodosaria subspinosa* Cushman
*Ellipsopleurostomella schlichti* Silvestri
*Entosolenia acuta* (Reuss) var. *bisenta* Cushman and Stainforth
*Entosolemia flintiana* (Cushman) var. *indomita* Cushman and Stainforth
*Entosolenia globoso* (Montagu) var. *spinulosa* (Reuss)
*Entosolenia pannosa* Cushman and Stainforth
*Globulina inaequalis* Reuss var. *caribaea* d'Orbigny
*Karreriella alticamera* Cushman and Stainforth
*Karreriella subcylindrica* (Nuttall)
*Lagena pulcherrima* Cushman and Jarvis var. *enitens* Cushman and Stainforth
*Marginulina laeviuscula* Cushman and Bermudez
*Nodosarella subnodosa* (Guppy)
*Planulina illingi* (Nuttall)
*Pyrulina extensa* (Cushman
*Trochamminoides irregularis* White

Similarly, the following are facies-markers for the San Fernando formation and probably of many of its regional equivalents, for example, Alazan of Mexico and Adelina of Cuba.

*Ammospirata mexicana* (Nuttall)
*Ceratobulimina* spp.
*Frondicularia tenuissima* Hantken
*Plectofrondicularia miocenica* Cushman
*Pseudoglandulina conica* (Neugeboren)
*Uvigerina curta* Cushman and Jarvis
*Vaginulina elegans* d'Orbigny var. *mexicana* Nuttall and others unidentified

The Ste. Croix and Esmeralda contain broadly similar faunas, characterized by *Siphogenerinas* of the *S. transversa* group. The Nariva clays carry arenaceous faunas with abundance of a distinctive *Eggerella* sp. scarcely known in other formations. Hedberg and Pyre (28, pp. 21–24, 27, figs. 3, 4) have shown that in the Santa Ines formation of the State of Anzoategui, Venezuela, the Capiricual member is a lithological counterpart of the Nariva formation of Trinidad and also contains a fauna characterized by *Eggerella* sp., and that at the southeast the Capiricual grades laterally into the Carapita shale, which is at least in part a lithological counterpart of the Esmeralda member and, moreover, contains the same facies-(and time-) markers (27, p. 686; 45, p. 546). By close analogy with Trinidad stratigraphy it seems probable that this is a case where attention to distribution of facies-markers among the Foraminifera would give a more precise picture of sedimentary intergradation than would superficial lithological studies.

## AGE OF CIPERO FORMATION

The faunas of the Cipero formation consist almost entirely of smaller Foraminifera which are not well suited to direct age determinations, owing to paucity of approximately synchronous homeotopic faunas elsewhere in the Caribbean

region and tropical America. From the extinction of *Hantkenina* and other typical upper Eocene (Jacksonian) species at the base of Zone I and from the occurrence of a probably upper Oligocene mollusk fauna in Zone III it is clear that the duration of deposition of the formation approximately coincided with the Oligocene epoch. The most recent statement on the age of the Cipero formation is by Cushman and Stainforth (13, pp. 7, 10–12), quoted here *in extenso*, followed by some corroborative evidence from the Ste. Croix beds. In the reference quoted the Flat Rock tongue mollusks are utilized on the assumption that they are intermediate in age between Zones I and II but, as discussed earlier in this paper, this claim is not fully substantiated.

In foraminiferal literature a number of species from the Cipero section have been described. Nuttall (40) did not give locality details, but there are many Cipero forms in his list of species from the "Marl and Green Clays," which he grouped with other units as Oligo-Miocene. Cushman and collaborators (9, 10, 11, 12) gave more precise details of locality and stratigraphy in describing material collected at the Cipero type-section by the late P. W. Jarvis. Species from Zone I were described as from the Eocene "Lower Marl" of the Cipero Section, Station 10. The dark-colored beds between Zones I and II were designated the "Bamboo Clay" of the Cipero Section, Station 11, and usually diagnosed as Eocene, probably by confusion with the San Fernando formation at Point Bontour. One species (*Cassidulina spinifera* Cushman and Jarvis) was described as from the "Upper Marl" of the Cipero Section, and is probably from Jarvis Station 12, equivalent to our Zone II. Numerous species from the "Green Clay," variously described as Miocene, lower Miocene, and lower middle Miocene, came from Zones II and III. Where specifically mentioned, Jarvis Stations 13 and 14 indicate Zones III and II respectively.

The above age-determinations have been modified as a result of later work, in particular specialized studies of larger foraminifera and mollusks. A summary of present views on the age of the Cipero formation follows:

Zone I. Lower (*Globigerina concinna*) zone

Marls of this zone rest conformably on either the Hospital Hill marl or glauconitic orbitoidal marl of the San Fernando formation. The Hospital Hill marl is Upper Eocene, typified by the presence of *Hantkenina alabamensis* Cushman var. *primitiva* Cushman and Jarvis and, more rarely, *Bulimina jacksonensis* Cushman. These and other typical Upper Eocene species do not range up into Zone I. On this evidence the basal marls of Zone I are probably Lower Oligocene, but a late Upper Eocene age is not excluded because in the shallower water facies of the San Fernando formation *Hantkeninas* became extinct before the end of the Eocene epoch as judged by the distribution of larger foraminifera.

At Point Bontour and Vista Bella marls of Zone I rest on orbitoidal beds of the San Fernando formation. Until recently the whole San Fernando formation was regarded as Upper Eocene but B. Caudri, in private reports prepared for Trinidad Leaseholds Ltd., has shown that the Upper Eocene larger foraminifera do not reach the top of the formation, e.g.

*Operculinoides ocalanus* (Cushman)
*Operculinoides soldadensis* Vaughan and Cole
*Operculinoides kugleri* Vaughan and Cole
*Asterocyclina asterodisca* (Guppy)

whereas several Oligocene species appear in the topmost beds, e.g.

*Operculinoides semmesi* Vaughan and Cole var. *ciperensis* V. and C.
*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad)
*Lepidocyclina* (*Lepidocyclina*) *yurnagunensis* Cushman var. *morganopsis* Vaughan

*Lepidocyclina* (*Eulepidina*) *favosa* Cushman
*Lepidocyclina* (*Eulepidina*) *gigas* Cushman
*Lepidocyclina* (*Eulepidina*) *undosa* Cushman

These topmost beds of the San Fernando formation are thus shown to represent the base of the Oligocene. The conformably overlying marls, low down in Zone I, are therefore placed in the Lower Oligocene. It should be noted, however, that deeper marls of Zone I are laterally equivalent to an undetermined thickness of the top of the San Fernando formation, hence a topmost Eocene age for the base of the zone remains possible.

The age of the top of the zone is established as not younger than Middle Oligocene by the fossil content of the "Bamboo Clay" which separates Zones I and II at the type section. From this bed Vaughan and Cole (56) determined the following larger foraminifera:

*Operculinoides semmesi* Vaughan and Cole var. *ciperensis* V. and C.
*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad)
*Lepidocyclina* (*Lepidocyclina*) *yurnagunensis* Cushman var. *morganopsis* Vaughan
*Lepidocyclina* (*Eulepidina*) *favosa* Cushman
*Lepidocyclina* (*Eulepidina*) *undosa* Cushman

Vaughan and Cole treated the Oligocene as a whole and determined the material they examined as Upper rather than Lower Oligocene. As this determination included numerous limestones known to be younger than the "Bamboo Clay," a Middle Oligocene age for the latter is not excluded. In particular *Lepidocyclina favosa* Cushman and *L. undosa* Cushman are described as common and widely distributed in the Middle Oligocene of the Caribbean region. In manuscript reports C. M. B. Caudri has recorded the following additional species from the "Bamboo Clay," for which she deduced a Middle Oligocene age:

*Lepidocyclina* (*Pliolepidina*) *subglobosa* Nuttall
*Lepidocyclina* (*Lepidocyclina*) *parvula* Cushman
*Lepidocyclina* (*Lepidocyclina*) aff. *canellei* Lemoine and Douvillé
*Lepidocyclina* (*Lepidocyclina*) *waylandvaughani* Cole
*Lepidocyclina* (*Eulepidina*) *gigas* Cushman var. *duncanensis* Cole

R. Rutsch, in unpublished reports (45) prepared for Trinidad Leaseholds Ltd., has described the mollusk faunas of the "Bamboo Clay." He lists:

*Acila* (*Truncacila* ?) *"schomburgki"* (Forbes)
*Limopsis* (*Pectunculina*) *subangularis frischknechti* Rutsch
*Propeamussium* (*Parvamussium*) *bronni pennyi* (Harris)
*Dentalium* (*Antalis*) aff. *mississippiensis* Conrad
*Cadulus caronensis* Mansfield ?
*Clio* (*Hyalocyclis ?*) aff. *maxima* (Ludwig)
*Turritella* aff. *altilira* Conrad

and numerous new or indeterminate forms. The age is determined as either Rupelian or Chattian.

In 1892 Guppy (18) described the Alley Creek shell-bed about half a mile south of the Cipero River mouth, but the outcrop seems to have been obscured in recent years. Marls at the locality indicated yield a Zone I foraminiferal fauna (Samples Rz. 114,142, Trinidad Leaseholds Ltd.). The recorded mollusks are partly endemic and do not assist in an age determination. They are:

*Carinaria caperata* Guppy
*Anomia umbonata* Guppy
*Dentalium* cf. *sexangulum* Schr. and indeterminate forms.

From the available evidence it is apparent that Zone I represents the Lower Oligocene but might include the topmost Eocene at its base and some Middle Oligocene in its upper half.

Zones II and III. Middle (*Globigerinatella insueta*) and upper (*Globorotalia fohsi*) zones

From their position above the "Bamboo Clay" these two zones are clearly not older than Middle Oligocene. *Globorotalia fohsi* Cushman and Ellisor is an Oligocene marker in the Agua Salada group of Venezuela (*fide* Renz, unpublished manuscript) and probably also in the Brasso formation of Trinidad. Various limestone lenticles in southern Trinidad, which are laterally equivalent to parts of Zones II and III, yield larger foraminifera, mollusks, echnoids, etc., which have been determined by specialists (45, 56) as Upper Oligocene for the most part and in one case (Meijas) Middle Oligocene.

Mollusks have been found in the marls of Zone III at Freeman's Bay, three or four miles south of the Cipero type section, where marlstone concretions contain an unusual mollusk fauna which has been listed as follows in an unpublished report (45) by R. Rutsch:

*Pleurophopsis unioides* Van Winkle
*Thyasira addocasa* Van Winkle
*Myrtea ? cookei* Olsson ?
*Lucina ? lomitensis* Olsson ?
*Solariella ? godineauensis* Van Winkle and indeterminate forms.

By tentative correlation with the Heath formation and Lomitos cherts of Peru, Rutsch gives a provisional age determination of Upper Oligocene.

On the foregoing evidence we may state that Zone II is of Middle to Upper Oligocene age and Zone III probably Upper Oligocene.

The "various limestone lenticles" referred to in the preceding extract from Cushman and Stainforth belong to the Ste. Croix beds and have yielded the faunas discussed as follows. As the Ste. Croix beds are interbedded with the upper parts of the Cipero formation, age determinations for the one are valid for the other.

*Morne Diablo and Quinam limestones.*—R. Rutsch, in a private report prepared for Trinidad Leaseholds Ltd. (45, p. 549), determined:

*Amusium* aff. *lyonii* (Gabb)
*Lithophaga nigra* (d'Orbigny)
*Pecten* (*Lyropecten*) aff. *condylomatus* Dall
"*Kuphus*" aff. *incrassatus* (Gabb)
*Phacoides* (*Miltha*) aff. *hillsboroensis* (Heilprin)
*Turritella* sp. aff. *altilira* Conrad
*Hipponyx* (*Rothpletzia*) *wiedenmayeri* (Hodson and Harris)
*Cassis* cf. *sulcifera* Sowerby and numerous new and doubtful species.

Rutsch determined the age of this mollusk assemblage as somewhat younger than the Antigua formation (Rupelian) and probably older than the Anguilla (Aquitanian), thus corresponding approximately with Chattian. From the same locality Vaughan and Cole, (56, p. 28) and C. M. B. Caudri (private report) have listed the following species of larger Foraminifera.

*Lepidocyclina* (*Lepidocyclina*) *forresti* Vaughan
*Lepidocyclina* (*Lepidocyclina*) *giraudi* R. Douvillé
*Lepidocyclina* (*Lepidocyclina*) *canellei* Lem. and Douv.
*Lepidocyclina* (*Lepidocyclina*) *parvula* Cushman
*Lepidocyclina* (*Lepidocyclina*) *pancanalis* Vaughan and Cole
*Operculinoides semmesi* Vaughan and Cole
*Operculinoides bullbrooki* Vaughan and Cole
*Miogypsina hawkinsi* Hodson
*Miogypsina bramletti* Gravell
*Miogypsina* aff. *primitiva* Tan
*Miogypsina mexicana* Nuttall
*Miogypsina staufferi* (Koch)

Vaughan and Cole included this fauna in their determination of upper rather than lower Oligocene. Caudri inferred an upper Oligocene age.

*Mejas limestone.*—Schilder (48) recorded the endemic cypraeid mollusk *Pustularia* (*Pustularia*) *mejasensis* Schilder, which he regarded as an Oligocene form, rather upper than lower. Vaughan and Cole (56, p. 28, Penal-Rock Road locality) and Caudri (private report) have listed the following larger Foraminifera.

*Lepidocyclina gigas* Cushman
*Lepidocyclina* (*Eulepidina*) *undosa* Cushman
*Lepidocyclina* (*Eulepidina*) *favosa* Cushman
*Lepidocyclina* (*Lepidocyclina*) *yurnagunensis* Cushman var. *morganopsis* Vaughan and Cole
*Lepidocyclina* (*Lepidocyclina*) *parvula* Cushman
*Lepidocyclina* (*Lepidocyclina*) *asterodisca* (Nuttall)
*Lepidocyclina* (*Lepidocyclina*) *subglobosa* Nuttall
*Lepidocyclina* (*Lepidocyclina*) *supera* (Conrad
*Lepidocyclina* (*Lepidocyclina*) *canellei* Lem. and Douv.
*Operculinoides semmesi* Vaughan and Cole
*Operculinoides semmesi* var. *ciperensis* Vaughan and Cole
*Miogypsina gunteri* Cole
*Miogypsina complanata* Schlumberger
*Heterostegina antillea* Cushman

As in the case of the Flat Rock tongue, Vaughan and Cole's age determination might be read as middle Oligocene on account of the presence of *L. favosa* and *L. undosa*. Caudri gave the age as middle Oligocene, possibly intermediate between the Flat Rock tongue and the Kapur limestone.

*Kapur limestone* (*synonymous with Logeon limestone*).—Vaughan and Cole (56, p. 23) and Caudri (private report) determined the following larger Foraminifera from the limestone in the Ste. Croix beds at Kapur Ridge (Logeon) near Guayaguayare, southeast Trinidad.

*Lepidocyclina* (*Eulepidina*) *favosa* Cushman
*Lepidocyclina* (*Eulepidina*) *undosa* Cushman
*Lepidocyclina* (*Nephrolepidina*) *tempanii* Vaughan and Cole
*Lepidocyclina gigas* Cushman
*Lepidocyclina* (*Nephrolepidina*) cf. *verbeeki* (Newton and Holland)
*Miogypsina gunteri* Cole

Caudri considered this a top middle Oligocene assemblage.

*Lothinas limestone* (*Ste. Croix limestone auct.*)—The faunas listed came from the old quarry near Broomage trigonometrical station south of Princes Town, Trinidad Government Cadastral Coordinates E. 410,270 links, N. 224,500 links. Caudri (private report) examined the limestone and associated marly clays for larger Foraminifera, but found only *Socrites* and *Archaias*. From the absence of *Lepidocyclinas* she deduced that that the age might be younger than the Morne Diablo limestone, that is, topmost Oligocene or even Miocene, but pointed out that the absence of important forms might be due to the peculiar facies of deposition. Rutsch (47, also 45, p. 559) recorded the following pteropods.

*Vaginella* cf. *lapugyensis* Kittl.
*Cavolina audeninoi trinitatis* Rutsch
*Clio pulcherrima* (Mayer)
*Clio* cf. *lavaysea* Rutsch

These are closely similar to Burdigalian-Helvetian forms of the European Tertiary

but different from the middle and upper Miocene forms described from the Mexican Gulf and Antillean region by Collins (3). Later, in a private report prepared for Trinidad Leaseholds Ltd., Rutsch determined further mollusks from the Lothians limestone, including:

*Limopsis* (*Pectunculina*) *subangularis* Guppy and Dall subsp. *frischknechti* Rutsch
*Typhis* aff. *alatus obesus* Sowerby
*Nemocardium* aff. *jamaicense* Dall
*Propeamussium bronni pennyi* (Harris)

His final age-determination was probably Burdigalian but possibly Aquitanian. Keen (30, p. 62) recently placed *Typhis alatus* in subgenus *Talityphis*, tentatively suggested as a side-branch developed from the *Typhinellus—Typhisopsis* line in late Oligocene to early Miocene time. Schilder (48) recorded the cypraeid mollusks.

*Sphaerocypraea wegeneri* Sch.
*Cypraeorbis perplexa* Sch.
*Jousseaumea joosi* Sch.
*Lurian* (*Basiliirona*) *sanctesebastiani adivinanzensis* Sch.

He placed the assemblage in the Burdigalian, although the evidence cited is not convincing, an Aquitanian age appearing equally acceptable. After studying the coral faunas Vaughan and Hoffmeister gave a list which is largely an emendation of Duncan's determinations (14). This coral fauna contains numerous endemic forms and gives no reliable guide as to age.

In summary of the foregoing evidence, there is sufficient at hand for a broad age determination of the limestone lenses of the Ste. Croix beds, and hence of the upper part of the Cipero formation, although large collections of fossils still await study by specialists. In addition to the mollusks and larger Foraminifera the faunas contain echinoids, corals, fish-teeth and other forms which should be considered before a final opinion about age is given. The present tendency is to place all the limestones among the deposits of the upper half of the Oligocene epoch.

The long-standing tendency to suggest a lower Miocene age for the Lothians limestone (Ste. Croix limestone *auct.*) dates back to the stratigraphically faulty inclusion of this unit with the Guaracara-type limestones of the Central Range, all of which are Miocene, mostly middle Miocene. The rich foraminiferal fauna of the marly clays interbedded with the Lothians limestone includes many species usually regarded as rigid Oligocene markers in the Caribbean-Antillean region. On the other hand, as Rutsch has pointed out, the pteropods suggest direct correlation with the Burdigalian of Europe. The same problem exists in Venezuela, where the pteropod *Clio pulcherrima* was recorded by Rutsch in Senn's $A_3$ Zone of the "Aguasalada-Tone" (49, p. 77), which H. H. Renz places in the upper Oligocene, equivalent to the *Globorotalia fohsi* zone of the Cipero formation (manuscript in press).

### RELATION OF CIPERO TO ADJACENT FORMATIONS

The stratigraphic significance of the Cipero formation can only be clearly assessed when the paleogeographic history of the Naparima Basin is understood.

A very brief history of Tertiary sedimentation in this region is here given. The stratigraphic nomenclature used is based on that of Renz 1942 (45), which differs in several respects from earlier references. These changes introduced by Renz in his excellent but highly compressed summary are well justified, but it would be a digression from the main theme of this paper to indulge in a general discussion of the matter at this point.

The Naparima Basin lies between the Central and Southern Ranges of Trinidad and is largely represented by marine marls of Upper Cretaceous to late Oligocene age. In the region of the present Central Range thick shales were laid down in Upper Cretaceous time and are now known as the Chaudiere and Tarouba formations. During Upper Cretaceous time the Central Range commenced to rise, forming the northern rim of a narrow basin. This was the incipience of the Naparima Basin. In early Miocene time deltaic sediments from the direction of the present Orinoco began to invade the area and by middle Miocene time had

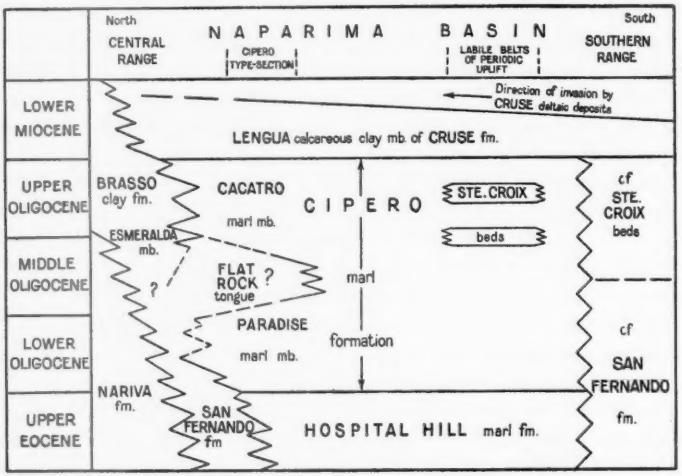



FIG. 2.—Chart showing stratigraphic relations between Cipero and adjacent formations.

virtually eliminated the basinal form. The Southern Range trend is treated as the southern rim of the basin, as we have evidence of shallow marine and reefal conditions there intermittently during early and middle Tertiary time, though it was not such a well developed barrier as the Central Range.

During its existence the Naparima Basin was not affected by any major orogeny, but epeirogenic movements of two types led to remarkable changes of facies which are the bugbear of stratigraphic work in this area. Firstly the northern rim of the basin rose gradually from Upper Cretaceous to upper Eocene time, then

steadily subsided during Oligocene time. Secondly there were periodic localized uplifts in the form of adjustment to sedimentary load: these were confined to certain well defined "labile belts" (Kugler, 31) which probably mark pre-Cretaceous structures in the floor of the basin. The southern rim of the basin was affected in a manner intermediate between that of the northern rim and of one of the labile belts.

The sediments of the Naparima Basin fall into three main categories: the peripheral deposits, the basinal deposits, and deposits developed only on submarine uplifts. The principal formations are listed below under these three headings. In this list and the following pages the terms applied to the benthic division of the marine environment follow the usage of Sverdrup, Fleming, and Johnson (50). The two main systems are the *littoral* and the *deep-sea*, the demarcation falling rather approximately at the outer edge of the Continental Shelf and at the depth of maximum penetration of sunlight. The littoral system is divided into the *eulittoral* zone, extending from high water-mark to 40–60 meters depth, and the *sublittoral* zone which is the deeper portion. The upper part of the deep-sea system, ranging down to depths of the order of 1,000 meters, is termed the *archibenthic zone*.

PRINCIPAL LITHOLOGICAL UNITS OF NAPARIMA BASIN

Peripheral deposits[1]

- Esmeralda calcareous clay member of Brasso clay formation
  - Sublittoral facies
  - Middle to upper Oligocene
- Nariva arenaceous formation
  - Piedmont facies
  - Eo-Oligocene
- San Fernando sand-silt-clay formation
  - Littoral facies, locally reefal
  - Upper Eocene to early Oligocene
- Soldado limestone formation
  - Reefal and sub-reefal facies
  - Paleocene
- Chaudiere and Tarouba shale formations
  - *Cf.* Piedmont facies
  - Upper Cretaceouus

Basinal deposits[2]

- Naparima marl group
- Lengua calcareous clay member of Cruse formation.
  - Transitional from marl to deltaic facies
  - Lower Miocene
- Cipero marl formation
  - Archibenthic facies
  - Oligocene
- Hospital Hill marl formation
  - Archibenthic facies
  - Upper Eocene

[1] Certain Cretaceous beds omitted since only known as exotic blocks in Eocene conglomerates. It should be noted that no peripheral deposits are definitely known of an age intermediate between Paleocene and upper Eocene. They were eroded almost as soon as laid down because epeirogenic movement lifted them into the strand zone.

[2] The basinal deposits were hardly affected by peripheral erosion during uplift ,and marls therefore exist of all ages from Upper Cretaceous to early Miocene.

Navet marl formation
Archibenthic facies
Lower to middle Eocene
Marl at Soldado Rock
Archibenthic facies
Paleocene
Lizard Springs marl formation
Archibenthic facies
Upper Cretaceous to Paleocene
"Brighton chalk," etc.
Archibenthic facies
Upper Cretaceous

Deposits on submarine uplifts
The Ste. Croix beds, an inclusive term for all lenses of shallow-water deposits enclosed by marl. Representative developments include: the limestones of Lothians (Ste. Croix *auct.*). Morne Diablo, Quinam, Kapur and Mejas: pepper-and-salt sands typified by the Herrera sands: associated clays.
Known examples are middle to upper Oligocene but older lenses may occur in subsurface deposits

The foregoing is a brief summary to show the general relationships of the Cipero formation to other sediments in the Naparima Basin. The recognition of three groups of formations is essential for paleogeographic work and must be carefully upheld in the cases of such closely similar but differently orientated beds as the calcareous clays of the Esmeralda and Ste. Croix or the non-calcareous clays of the Ste. Croix, Nariva, and Cruse. A more detailed discussion follows, of the physical relationships between the Cipero and intimately adjacent formations.

### NARIVA FORMATION

The Nariva formation consists dominantly of grits and shales which crop out in a strip traceable across Trinidad on the south flank of the Central Range. It represents a piedmont facies and is formed primarily of sediments derived by erosion of the old Central Range landmass.

The lateral transition from the Nariva to the Cipero formation is direct in some places, while in others an intermediate formation is present, either the San Fernando or Brasso (Esmeralda member). South of Piparo (10 miles east of Pointe-a-Pierre) the direct transition is well exemplified in beds containing the time-marker Foraminifera of the *Globorotalia fohsi* zone. From north to south a lithological gradation is seen from rusty-weathering Nariva clays with sandy layers through less ferruginous non-sandy clays which show an increasing lime content until the true Cipero marls are reached in the south. There is a corresponding gradation in foraminiferal faunas from wholly arenaceous assemblages in the Nariva, through arenaceous with a sprinkling of *Nodosarias* and *Globigerinas* to the rich calcareous assemblages of the Cipero. East of San Fernando Cipero marls of the *Globigerina concinna* zone interdigitate with non-calcareous Nariva clays. Good exposures of this lateral transition were to be seen in the road-bed cut for the new by-pass in 1945.

The indirect Cipero-Nariva transition takes place through an intermediate development of either the San Fernando formation or the ecologically similar

Esmeralda member. The former is well exemplified at many sections around San Fernando, for example, in cuts north of the railway station, and the latter at many points along the southern foot of the Central Range, including the type area near Esmeralda Estate, 8 miles east-northeast of Pointe-a-Pierre. In both cases there is a simple lateral gradation and interdigitation, demonstrable by lithological and faunal changes.

The northward gradation from the Cipero into one of the peripheral formations marks the change from archibenthic to sublittoral facies and is principally a function of sea-floor configuration. Whether the sublittoral facies should be represented by the San Fernando-Esmeralda or by the Nariva type of deposits is suspected to have been controlled by the clarity or turbidity of surface waters. There is considerable evidence that the San Fernando and Esmeralda were formed under warm, shallow to medium depth, clear-water conditions: abundance of orbitoids in the former and of large costate *Siphogenerinas* in the latter are significant factors. On the other hand the purely arenaceous character of the Nariva foraminiferal faunas may indicate turbidity of the waters beneath which the shales accumulated. This suggestion is based on the homeotopy of the faunas of the Nariva clays, certain non-calcareous clays in the Ste. Croix, and the clays of the Cruse formation of southern Trinidad, all three of which are rich in rather large species of such genera as *Cyclammina*, *Goësella*, *Valvulina*, *Rhabdammina*, *Hormosina*, but contain practically no calcareous Foraminifera. The similarity and distinctive character of these three faunas must denote some important ecological factor which influenced the deposition of all three units. Current opinion as to their milieus of deposition is:

| | |
|---|---|
| Nariva formation | Near-shore deposition of terrigenous material—piedmont facies |
| Ste. Croix non-calcareous clays | Re-deposition of local submarine mudflow exudation in the open sea |
| Cruse clays | Rapid flocculation of highly colloidal clay matter on fringes of major delta |

One readily apparent factor common to all three environments is that of turbidity caused by an abundance of suspended clay matter. Such turbidity, being hostile to the photosynthetic activity of phytoplankton, could lead to low carbonate-ion concentration and hence indirectly to absence of calcareous organisms. The empirical law suggests itself that the San Fernando-Esmeralda type of clear-water facies could only develop where the sea-floor contour marking the upper limit of marl (Cipero) deposition lay beyond the seaward extension of the turbid-water province of Nariva deposition, elsewhere the transition from the Nariva to the marls would be direct.

### SAN FERNANDO FORMATION

The San Fernando formation shows all the lateral variation associated with littoral facies. Conglomerates and sandstones, not greatly different from parts of the Nariva, evidently indicate strandline conditions. They grade laterally into a complex of glauconitic marls and clays, including highly orbitoidal beds and

biohermal reef limestones. These in turn pass laterally into light-colored marls of the Naparima group, including the lower part of the Cipero formation. The lateral passage is transitional and not precisely definable, but limonitic weathering is conspicuous in the San Fernando and the transitional beds. Interdigitation of the different lithological types is common near the main facies-boundary.

The name Flat Rock tongue has been introduced in this paper to replace the unsatisfactory names used previously. The origin of the much used name "Bamboo clay" (9, 13, 31, 34) lay in a fanciful resemblance of the long *Nodosaria longiscata* to bamboo stalks, and did not refer to any topographic feature. Lehner's more orthodox suggestion of "Cipero silt" is considered pre-empted by Thomas' broader usage (51). Flat Rock is the local name for the area around the southern end of the San Fernando sea-wall. The bed in question contains an important fossil fauna, but as exposed is isolated by faults and truncated by the coast-line, so that its stratigraphic classification must be inferential. The author refers it to the San Fernando formation on lithological grounds, strongly supported by an extremely close similarity in faunal constitution, indicative of a very similar facies of deposition.

Certain beds in the Southern Range, only known from small patches in discordant anticlinal cores, show close resemblance to the San Fernando formation of the Central Range. In Figure 2 they are entered as "*cf.* San Fernando formation."

#### ESMERALDA MEMBER

The Brasso formation is largely confined to the Northern Basin of Trinidad, developed north of the Central Range by regional subsidence during the Oligocene epoch. The basal Esmeralda member, however, shows limited development south of the Central Range, thought to indicate a decadent archipelagic state of the old Central Range landmass allowing free marine communication between the Northern and Naparima basins.

In the latter the Esmeralda member represents a peripheral sublittoral facies contemporaneous with the younger part of the Cipero marls. Their relationship is one of simple lateral transition, characterized by interdigitation of marls with calcareous clays. The transitional features can be traced sporadically along a strip parallel with and south of the Central Range axis. The northern (shoreward) margin of the Esmeralda member is marked by lateral passage into sands and clays marking the senescent stage of Nariva deposition. In places the Esmeralda clays are directly transgressive on to the older rocks of the Central Range, an early symptom of complete transgression of the Brasso formation over the quondam land area of the Central Range.

#### STE. CROIX BEDS

The beds included under the name Ste. Croix show close similarity to the various peripheral deposits classed as Nariva and Esmeralda, but they are so

intimately related to the archibenthic Cipero marls that their mode of origin is not so simply explained. Illing (29, p. 21), for instance, referred to the anticline north of Retrench, in which he noted three good sands interbedded with radiolarian marl. Old wells in the Naparima area showed lenticular sands interbedded in Cipero marl. Illing considered the oscillation requisite for alternation of shallow-water sands and deep-water marls too drastic to be credible, and therefore postulated that the marls must actually be shallow-water deposits of a pseudo-bathyal type produced by current transport of oceanic plankton into a shallow embayment. His case was strengthened by his own belief that the marl province was only a narrow strip, 20 or more miles in length but rarely more than 5 in width.

There is now ample evidence that, discounting lenticular inclusions of the Ste. Croix beds, the Cipero marls covered the whole area between the Central and Southern ranges of Trinidad. Their faunal and lithological uniformity over such a wide expanse and their clearly established place in the sequence of homologous Naparima marls point rather strongly to an extra-littoral origin for the Cipero marls. Seemingly conclusive evidence is found in the ecologic character of the molluscan and foraminiferal faunas, as discussed in a later section. Comparatively few species of Foraminifera are planktonic and Illing's theory of current transport would not account for the constant fraction of bottom-living forms in the Cipero faunas.

The known developments of the Ste. Croix beds are confined to the labile belts of Kugler (31), the axes of ancient structural weaknesses in the floor of the Naparima Basin. These have repeatedly been the focal lines of orogenic activity, commonly in the form of anticlinal upthrusts with pseudo-diapyric cores of late Cretaceous or early Eocene marls, or in the extreme case with axial extrusions of heterogeneous mudflow material. The anomaly of the shallow-water aspect of lenses of the Ste. Croix beds enclosed in archibenthic Cipero marls is explained as due to deposition of the Ste. Croix beds on sea-floor highs at times of orogenic uplift along the labile belts. Reef-limestones were formed along the crests of submarine ridges produced by orogeny, and were flanked by calcareous clays transitional laterally into the marls. Conglomeratic sands and clays were perhaps derived from local submarine effusion of mudflow.

### CONDITIONS OF DEPOSITION OF CIPERO FORMATION

The northern margin of the Naparima Basin is characterized by a north-south lateral transition from the Nariva formation directly, or else indirectly through the San Fernando formation or Esmeralda member, into the Cipero marls. In ecological terms this is a transition from a eulittoral through a sublittoral to an archibenthic facies-province.

The Nariva formation is typified by presence of conglomerates, massive, coarse-grained grits, ripple-marked flaggy sandstones, and muddy shales, all indicative of near-shore conditions. Southward the San Fernando formation and

Esmeralda member both contain faunas representative of sublittoral facies. The Esmeralda faunas, for instance, contain large costate *Siphogenerinas* in abundance, the San Fernando assemblage a comparable plenitude of orbitoids, while both yield numerous remains of phyla other than Foraminifera—mollusks, echinoids, crustacea, *et cetera*. Pelagic Foraminifera are common but by no means dominant in the faunas.

In contrast the faunas of the Cipero marls consist almost exclusively of Foraminifera: echinoid spines, ostracods, and fragments of thin-shelled mollusks are negligible in quantity. More than 90 per cent by numbers of the Foraminifera belong to pelagic species. H. H. Renz, in experiments made to ascertain the minimum depth of auger-holes required to obtain unweathered samples, has shown (private report) that the curve of $CaCO_3$ content of the Cipero marls runs parallel with the curve expressive of the number of Foraminifera per unit weight of dried marl. In other words the free carbonate content of the marls is almost entirely in the form of fossil Foraminifera. Renz' figures for a series of closely spaced Cacatro marl samples show that ordinarily 550 to 750 individuals per 100 gms. of dried marl are present per unit per cent of calcium carbonate, though there is some fluctuation in the results owing to variation from sample to sample in the average size of Foraminifera present and in the proportion of fragmentary tests.

The following figures for calcium carbonate content of several sets of Cipero marl samples are based on Schrötter measurements by D. J. Miller (now Mrs. G. R. Brotherhood) in the geological laboratory of Trinidad Leaseholds Ltd.

| *Stratigraphic Unit* | *No. of Samples* | *Calcium Carbonate Content (Percentage)* | |
|---|---|---|---|
| | | *Range of Variation* | *Average* |
| Paradise marl | 9 | 14.1–32.1 | 24.1 |
| Paradise marl | 20 | 16.2–43.8 | 34.8 |
| Paradise marl | 9 | 22.8–47.0 | 30.2 |
| Cacatro marl (Zone II) | 3 | 40.9–59.3 | 50.6 |
| Cacatro marl (Zone III) | 42 | 11.1–51.2 | 32.1 |
| Retrench beds | 2 | 18.8–19.1 | 19.0 |
| Totals | 85 | 11.1–59.3 | 32.1 |

An overall average for the Cipero formation as a whole is 32 per cent calcium carbonate content, which as already stated consists mainly of foraminiferal tests. Counts of several thousand Foraminifera in random samples of Cipero marl gave the following results:

Zone I. Several hundred pelagic to each benthonic specimen
Zone II. 2,197 pelagic to 37 benthonic specimens (59:1)
Zone III. 2,984 pelagic to 119 benthonic specimens (25:1)

Modern *Globigerina* oozes have been defined as consisting to at least 25 per cent by dried weight of unbroken Foraminifera with an average ratio of 25–28:1

pelagic to benthonic specimens (50, p. 984, 985). The Cipero formation appears to fulfill the requirements of a fossilized *Globigerina* ooze and the tendency is therefore to class it as a deep-sea (archibenthic) deposit. The lateral transition from San Fernando or Esmeralda calcareous clays to Cipero marls clearly marks deposition near the sea-floor contour demarcating a shallower sublittoral facies and a deeper archibenthic facies. Ekman's compilations (50, p. 277) for recent oceans show that this depth may be as much as 400 meters in tropical regions but is rarely deeper and in temperate regions is nearer 200 meters because of weaker penetration of the sunlight essential for photosynthesis.

Many records of *Globigerina* oozes in the present oceans are from great depths but it is contrary to other evidence to postulate for the Cipero sea such depths as given in the compilations of Sir John Murray, which register a minimum recorded depth of 777 meters but an average of 3,612 meters for *Globigerina* ooze (50, p. 978), or of Thorp (35) who in a list of 156 samples from the western North Atlantic and the Caribbean Sea recorded no *Globigerina* ooze from less than 1,500 meters. Brady (2) listed 25 widely dispersed stations at which *Globigerina* ooze was dredged: their average depth was 1,465 fathoms but at two stations (Nos. 166, 174A) in the Pacific the samples were dredged at a depth of only 450–500 meters (255 and 275 fathoms).

Woolnough (61) has made pertinent comments on uncritical extrapolation from modern oceanographic observations to paleogeographic inferences, claiming that ecological comparison between Recent and fossil assemblages is only justified when it is known that the types of sea and the orogenic states of the surrounding landmasses are the same. In the present instance it is known that the Antillean sea of Eo-Oligocene time was of tropical character with archipelagic islands, much as it is to-day. Deductions based on comparisons between present-day littoral deposits and their Tertiary counterparts give a logical and coherent picture of this ancient sea, and the result of applying the same deductive processes to the deeper-water deposits should be equally valid. These comments apply to the following section, in which inferences as to the mode of deposition of the Cipero formation are drawn from comparisons of Recent and fossil Foraminifera.

The paleoecology of the Foraminifera is far from being a well established branch of science because of inadequate oceanographic data, the personal factor in determining species and classifying families, lack of statistical control, and other factors. However, various authors have demonstrated fairly constant relationships between bottom-depth and bottom-temperature and faunal constitution. Norton's well known paper (39) gives detailed and summarized analyses of samples mostly from the Floridan-West Indian region, representing a wide bathymetric range. Despite the small number of his samples (15) Norton's main conclusions have mostly been confirmed by subsequent workers. As regards individual species he recorded the following 35 which were also recorded from the Cipero formation by Cushman and Stainforth (13). The numbers after each name refer to the Norton samples (29, pp. 331, 332) in which that species was recorded.

*Rhabdammina discreta* Brady (11)
*Saccammina sphaerica* Sars (9, 11)
*Hormosina globulifera* Brady (11)
*Ammodiscus incertus* (d'Orbigny) (12, 13)
*Ammolagena clavata* (Parker and Jones) (11)
*Cyclammina cancellata* Brady (11, 13)
*Gaudryina flintii* Cushman (9, 11, 13)
*Sigmoilina schlumbergeri* Silvestri (9, 10, 11, 13)
*Triloculina trigonula* (Lamarck) (4, 5, 6, 7, 8, 9, 13)
*Pyrgo murrhina* (Schwager) (6, 9, 10, 13)
*Robulus occidentalis* (Cushman) var. *torridus* (Cushman) (9, 11)
*Saracenaria acutiauricularis* (Fichtel and Moll) (9)
*Lagena laevis* (Montagu) (13)
*Nonion pompilioides* (Fichtel and Moll) (14, 15)
*Entosolenia marginata* (Walker and Boys) (12)
*Entosolenia globosa* (Montagu) (11)
*Entosolenia orbignyana* (Sequenza) var. (15)
*Entosolenia flintiana* (Cushman) (15)
*Bolivina beyrichi* Reuss (11)
*Uvigerina auberiana* d'Orbigny var. (10, 14)
*Trifarina bradyi* Cushman (10)
*Eponides umbonatus* (Reuss) (3, 10, 12, 13, 14, 15)
*Siphonina pulchra* Cushman (4, 6, 7, 8, 9, 10, 13)
*Pulvinulinella "culter"* (10, 11, 12, 13)
*Cassidulina subglobosa* Brady (9, 10, 11, 12, 13, 14)
*Ehrenbergina* sp. (11, 12, 13)
*Pullenia quinqueloba* (Reuss) (10, 11, 13, 14, 15)
*Globigerina inflata* d'Orbigny (9, 10, 11, 12, 13, 14, 15)
*Globigerina bulloides* d'Orbigny (8, 9, 10, 11, 12, 13, 14, 15)
*Globigerinoides rubra* (d'Orbigny) (6, 8, 9, 10, 11, 12, 13, 14, 15)
*Globigerinoides succulifera* (Brady) (1, 9, 10, 11, 12, 13, 14, 15)
*Globigerinoides conglobata* (Brady) (9, 10, 11, 12, 13, 14, 15)
*Candorbulina universa* Jedlitschka (9, 10, 11, 12, 13, 14, 15)
*Globorotalia canariensis* (d'Orbigny) (10, 13, 14, 15)
*Laticarinina* sp. (10, 11, 13)

The implication of these records is that the Cipero faunas correspond with those of the Norton samples 9–15, especially with Nos. 9, 10, 11, and 13, and have very little in common with samples 1–8.

Comparison of the statistical composition of faunas leads to the same conclusion. The list on p. 1323 shows the relative dominance of families in the Cipero faunas, indicating the number of species and varieties per family expressed as a percentage of the whole fauna (257 forms) as described by Cushman and Stainforth (13). The list is annotated to indicate affinities between the Cipero fauna and the Norton samples.

The cumulative inference from these data is that the Cipero fauna represents a milieu rather deeper than Norton's Station No. 9, yet a distinct affinity to this station is shown by the evidence of several families, including the Buliminidae and Lagenidae which together form 36 per cent of the Cipero fauna. It should be noted that the Ellipsoidinidae were not recorded by Norton, and the Heterohelicidae were negligible in his faunas, although these two families jointly form a fifth of the Cipero fauna.

The foregoing paragraph considers the simplest and most used form of statistical analysis of foraminiferal faunas. It is open to the objection that it gives a

| *Family* | *No. of Species and Varieties as Percentage of Cipero Fauna* | *Notes on Affinities to Norton's Stations (Op. Cit., Table 2, p. 360)* |
|---|---|---|
| Astrorhizidae | 0.8 | Recorded only at Nos. 11 and 13 |
| Rhizamminidae | 0.4 | Recorded only at No. 4 |
| Saccamminidae | 0.4 | *Cf.* No. 9. Recorded only at 9 and 11 |
| Hyperamminidae | 0.4 | *Cf.* No. 12. Recorded only at 11–13 |
| Reophacidae | 0.8 | *Cf.* Nos. 7, 9, and 13 |
| Ammodiscidae | 1.6 | *Cf.* Nos. 11, 12, and 13 |
| Lituolidae | 1.6 | No clear analogy |
| Textulariidae | 1.6 | No clear analogy but suggests either deeper or shallower than Nos. 8 and 9 |
| Verneuilinidae | 1.6 | No clear analogy but suggests shallower than No. 10 |
| Valvulinidae | 3.5 | *Cf.* No. 2 or 5 |
| Miliolidae | 2.9 | Distinctly lower value than any recorded by Norton |
| Lagenidae | 20.8 | *Cf.* Nos. 9 and 15 |
| Polymorphinidae | 6.6 | *Cf.* No. 8 |
| Nonionidae | 0.8 | Suggests deeper than No. 9 |
| Heterohelicidae | 5.5 | No analogy. Only recorded in Nos. 1 and 6 |
| Buliminidae | 15.2 | Rather higher percentage than highest recorded, *i.e.*, Nos. 9 and 10 |
| Ellipsoidinidae | 14.4 | No analogy. Not recorded |
| Rotaliidae | 3.5 | No close analogy, but *cf.* Nos. 9–13 |
| Cassiduliniidae | 4.3 | *Cf.* Nos. 9–15, especially No. 10 |
| Chilostomellidae | 2.3 | *Cf.* No. 10 and deeper |
| Globigerinidae | 4.7 | Deeper than No. 8 |
| Globorotaliidae | 1.6 | No clear analogy. Suggests No. 8 or shallower |
| Anomalinidae | 4.7 | No clear analogy |
| | 100.0 | |

distorted picture of the fauna because a family such as the Globigerinidae, which forms well over 90 per cent by number of specimens of the Cipero fauna, is made to appear of small importance (4.7 per cent), whereas a family such as the Lagenidae, which by actual count forms less than 0.1 per cent of the fauna but includes many species and varieties, is given an inflated importance (20.8 per cent). It is worthy of note in this connection that, of the total species and varieties in the Cipero fauna, unicellular forms number 37—more than 14 per cent—although in number of specimens their contribution to the bulk of the fauna is negligible. Inasmuch as many of these forms are classed almost optionally under the genera *Lagena* (Lagenidae) or *Entosolenia* (Buliminidae) their presence can lead to distortion of the statistical tables.

The statistical analysis of a microfauna by actual counting is at best a tedious process. In the case of the Cipero the overwhelming abundance of pelagic specimens would make it necessary to count from 10,000 to 20,000 specimens from each of several random samples to obtain reliable figures for the relative abundance of specimens in the benthonic families. Otherwise the probable error would exceed the stated differences in percentage frequency between different families. Norton overcame this difficulty by applying numerical values to the frequency signs applied in analysis of samples, namely, Rare, 1; Common 10; Abundant, 100.

In the following table are given relative frequencies of specimens of different families in the Cipero faunas based on the same method of computation. The Globigerinidae and Globorotaliidae were excluded in computing the percentages, and the comparisons made refer to Norton's figures re-calculated to exclude these two pelagic families. Separate figures are given for the three zones of the Cipero formation because of significant differences in family-frequency.

| *Percentage of Specimens per Family in Samples of Cipero Marl, Pelagic Forms Excluded* | | | | *Notes on Affinities with Norton's Stations (Op. Cit., Table 5, p. 366)* |
|---|---|---|---|---|
| | *Zone I* | *Zone II* | *Zone III* | |
| Astrorhizidae | 0.2 | 0.2 | 0.3 | *Cf.* No. 13 |
| Rhizamminidae | 0.9 | — | — | No clear analogy |
| Saccamminidae | 0.9 | — | — | No clear analogy |
| Hyperamminidae | 0.2 | — | — | No clear analogy |
| Reophacidae | 1.7 | — | — | No clear analogy |
| Ammodiscidae | 11.2 | 0.5 | 1.6 | For Zones II, III *cf.* Nos. 11–13. For Zone I no analogy |
| Lituolidae | 1.9 | 0.3 | 1.6 | On average *cf.* Nos. 10 and 13 |
| Textulariidae | 1.3 | 2.5 | 2.6 | *Cf.* Nos. 10 and 11 (or shallow stations Nos. 1–4) |
| Verneuilinidae | 1.3 | 0.3 | 0.7 | *Cf.* No. 9 and shallower |
| Valvulinidae | 4.3 | 4.4 | 4.1 | Comparable only with Nos. 1 and 2 |
| Miliolidae | 2.9 | 2.7 | 3.1 | No analogy |
| Lagenidae | 9.0 | 23.2 | 16.9 | No. 9 and deeper |
| Polymorphinidae | 1.2 | 2.4 | 4.4 | No clear analogy |
| Nonionidae | 1.6 | 0.2 | 0.3 | No. 9 and deeper |
| Heterohelicidae | 2.1 | 3.3 | 4.4 | No analogy |
| Buliminidae | 9.4 | 10.2 | 15.7 | *Cf.* No. 10 |
| Ellipsoidinidae | 14.6 | 25.0 | 14.4 | No analogy (not recorded) |
| Rotaliidae | 4.5 | 4.9 | 5.4 | *Cf.* Nos. 7 to 10 |
| Cassidulinidae | 13.0 | 2.0 | 2.4 | For Zone I, *cf.* Nos. 10 and 12. For Zones II and III, *cf.* Nos. 11 and 15 |
| Chilostomellidae | 2.6 | 8.9 | 11.6 | Analogy not good, but *cf.* No. 10–15 |
| Anomalinidae | 15.1 | 8.7 | 10.4 | *Cf.* Nos. 11–13 |

The general inference to be drawn is that the Cipero faunas show most analogy to Stations 10–13 of Norton, but there is also affinity to Station No. 9. Contradictory evidence of the Valvulinidae is outweighed by that of other families.

The fact that three different lines of approach give this same result must be significant, and on this basis it can be claimed that the Cipero faunas represent a depth of deposition intermediate between that of Norton's Station No. 9 and of his faunally similar Stations 10–13. Station No. 9 has a depth of 60 fathoms, temperature 20.6°C., whereas Stations 10–13 (Zone C of Norton) covered a depth range of 504 to 825 fathoms and a temperature range of 4.0° to 7.6°C. It is therefore suggested that the Cipero faunas lived at a depth between 120 and 1,000 meters at temperatures between 7° and 20°C.

This conclusion is supported independently by the studies of Natland off the Californian coast (38). Natland established five depth-temperature zones ranging from beach-level to more than 8,000 feet deep. The following 19 species of the Cipero fauna were included in his faunal list.

*Ammodiscus incertus* (d'Orbigny)
*Bolivina beyrichi* Reuss
*Cassidulina subglobosa* H. B. Brady
*Cassidulina crassa* d'Orbigny
*Cyclammina cancellata* H. B. Brady
*Dentalina soluta* Reuss
*Eponides umbonatus* (Reuss)
*Globigerina bulloides* d'Orbigny
*Globigerina inflata* d'Orbigny
*Globigerinoides rubra* (d'Orbigny)
*Globorotalia canariensis* (d'Orbigny)
*Haplophragmoides scitulum* (H. B. Brady)
*Lagena hispida* Reuss
*Lagena striata* d'Orbigny var.
*Laticarinina* spp.
(?) *Candorbulina universa* Jedlitschka
*Pullenia bulloides* (d'Orbigny)
*Pullenia quinqueloba* (Reuss)
*Pulvinulinella "culter"* (Parker and Jones)

Natland's distribution chart shows clearly that, as a group, these species indicate a zone overlapping the top of his Zone IV (depth 900–6,500 feet; temperature 8.5–4°C.) and the base of his Zone III depth 125–900 feet, temperature 13.2–8.5°C.). From this it can be inferred, assuming a more tropical latitude for Oligocene Trinidad than for present California, that the Cipero faunas lived at a mean depth of not less than 300 meters and a mean temperature of 8.5°C.

In addition to the inferences drawn from the Foraminifera, it is useful to find that other ecological features of the Cipero faunas indicate archibenthic conditions. For instance in a private report prepared for Trinidad Leaseholds Ltd., R. Rutsch makes the following comments on the Zone III mollusk fauna at Freeman's Bay.

> Large *Thyasirae* similar to those in the Freeman formation are today, so far as America is concerned, restricted to the cold water zone of the north of the United States. Their occurring in a region like Trinidad, whose other sediments contain pronouncedly tropical faunas, seems to point to the conclusion that here they must have lived at depths where they met with correspondingly low temperatures . . . . In Peru, *Pleurophopsis* is associated with mollusks of a pronounced deep-sea character (deep-sea in the sense of depths below the littoral region, not in the sense of abyssal) . . . . All these data therefore point to the conclusion that the Freeman formation is a deposit at considerable depths of the sea, roughly corresponding with the bathyal zone.

Further evidence as to the depth of deposition follows from mechanistic consideration of the Naparima Basin. It has been postulated in this paper that the Ste. Croix beds represent pseudo-sublittoral facies developed intermittently on parts of the sea floor that were forced above the minimum depth favorable to marl (*Globigerina* ooze) deposition. Vertical displacement of many hundreds of feet can not reasonably be considered, and the presence of Ste. Croix beds in various parts of the Naparima Basin therefore suggests that near these areas the Cipero marl was laid down at a depth little greater than the minimum at which such deposits could accumulate. As mentioned earlier the sublittoral-archibenthic facies boundary probably has a normal depth of 200 meters with maximum depths of 400 meters in clear tropical seas.

The inferred depth of deposition of the Cipero marls receives indirect support from consideration of the size of the Naparima Basin. The northern margin of the basin followed the Central Range trend and the southern margin followed the trend of the present Southern Range anticlinorium. On the west in Venezuela marls of the Naparima group are unknown and the Oligocene is represented by beds comparable to the sublittoral facies of Trinidad. The Naparima Basin was thus a finger-shaped arm of a sea or ocean which extended eastward from Trinidad. The width of the basin in its present-day structural status is 15 miles in western Trinidad and slightly more in the eastern part of the island. The tendency of orogenic deformation in Trinidad has been one of compaction in a trend approximately north and south. C. C. Wilson (59) explains this as due to gravity collapse of the sedimentary mass resting on the sloping rim of the Guiana Shield. Almost isoclinal folding and parallel thrusting in incompetent beds leave no doubt that the Naparima Basin was originally wider than it is now. Assuming an original width of perhaps 30 miles—twice the present figure—with a coast line in the north and a submarine barrier not deeper than 400 meters in the south, a central depth of approximately 1,000 meters would require an average sea-floor gradient steeper than 1 in 30. This is comparable only with the very steepest slopes in the present Caribbean sea floor. To allow for large submarine ridges within the basin, as seems necessary to account for the Ste. Croix beds, impossibly steep gradients would be required on their flanks unless a maximum depth of 400–500 meters were postulated for the Oligocene Naparima Basin.

The ecologic significance of Radiolaria-rich beds in the Cipero formation is not clearly understood. The modern tendency is to discount the old theory that the radiolarian earths were laid down at abyssal depths. Though neither so thick nor, ordinarily, so high in radiolarian content as the famous Barbados deposits, the Retrench beds of Trinidad are broadly similar to them. The writer can claim only a cursory acquaintance with the Oceanic formation of Barbados, but it has struck him as significant that the beds richest in radiolaria are closely associated with volcanic ash beds. From this it might be argued that the development of rich radiolarian faunas was related more to a temporary increase in available silica than to depth factors.[5]

In Trinidad the Retrench beds are known to occur in close lateral proximity to lenses of Ste. Croix beds. This eliminates any possibility that the radiolarian beds are of abyssal origin. A feasible relationship between the Ste. Croix beds and the Retrench beds is that the sea-floor upheavals which preceded depositions of Ste. Croix were local symptoms of a regional activity which was expressed elsewhere by volcanic extrusions, the ash from which settled on the surrounding sea and produced conditions temporarily favorable to dominance of Radiolaria and

[5] For a discussion of relationships between volcanism and radiolarian cherts, see Nicholas L. Taliaferro, "Franciscan-Knoxville Problem," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 2 (February, 1943), pp. 147–50.

other siliceous organisms in the marine faunas. Woolnough (61) cites comparable cases in the Pacific islands. Washed residues of the Retrench beds contain a lustrous, white, flaky clay-mineral not seen in normal Cipero residues: although a minor point, this can not be explained merely by postulating different depths of deposition.

In summary, it is suggested that the Cipero marl is a fossil *Globigerina* ooze deposited in the open sea at depths of 400–500 meters. No attempt has been made to relate the depositional history of the Cipero formation with the development of the Orinoco geosyncline, though this would be the next step in a broader study.

## REGIONAL CORRELATION OF CIPERO FORMATION

The Oligocene of the West Indies and the adjacent mainland of South and Central America is largely represented by sediments laid down in sublittoral facies, with closer affinities with the Esmeralda and San Fernando formation of Trinidad than with the archibenthic Cipero marls. The only exception to this statement of which we have definite cognizance is found in the Oceanic and other marls of Barbados, lithologically homologous with the Naparima marl group of Trinidad and faunally homeotopic. The youngest marls ascribed to the Oceanic formation of Barbados have been termed "Codrington College marl" by A. Senn (49-a, pp. 1584, 1586, and chart). They crop out in the Consetts section and are represented in the Trinidad Leaseholds collection by Senn pit-samples Nos. 203-B to 213, which cover a thickness of more than 100 meters of beds conformably overlying the upper Eocene part of the Oceanic formation. The faunas of these samples show a truly remarkable similarity to those of the Cipero marls of Trinidad. Species present which are used in zonation of the Cipero include an abundance of *Globigerina* cf. *concinna* Reuss and some specimens of:

*Buliminella grata* Parker and Bermudez
*Cassidulina caudriae* Cushman and Stainforth
*Discorbis ciperensis* Cushman and Stainforth
*Entosolenia flintiana* (Cushman) var. *plicatura* Cushman and Stainforth
*Lagena ciperensis* Cushman and Stainforth
*Lagena tetragona* Parker and Jones
*Rectogümbelina inopinata* Cushman and Stainforth
*Uvigerina capayana* Hedberg
*Uvigerina spinicostata* Cushman and Jarvis
*Vulvulina jarvisi* Cushman

The co-occurrence of these species leaves no doubt possible that the samples in question represent a precise equivalent in Barbados of Zone I (*Globigerina concinna* zone) of the Cipero formation. Subjacence of upper Eocene in both islands emphasizes the parallelism. The Codrington College marl has already been correlated by Senn, 1940, with the "Lower Cipero marl," that is, Zone I of Cushman and Stainforth, and with the lower Oligocene Guayaval marl of eastern Falcón, Venezuela (49-a, p. 1586 and chart).

Zone III of the Cipero formation has an equally close equivalent in Barbados, as first observed by A. Senn in some marls at the bottom of several water wells

which pierce the coral rock. In samples kindly supplied by A. Senn the following Foraminifera were noted which in Trinidad differentiate the joint Zone II and III faunas from that of Zone I:

*Bulimina tuxpamensis* Cole
*Ellipsonodosaria verneuili* (d'Orbigny) var. *paucistriata* Galloway and Morrey
*Globigerinatella insueta* Cushman and Stainforth
*Globigerinoides sacculifera* H. B. Brady
*Globorotalia praemenardii* Cushman and Stainforth
*Gyroidina alliformis* Cushman and Stainforth
*Schenckiella suteri* Cushman and Stainforth
*Siphogenerina basispinata* Cushman and Jarvis *et cetera*

Furthermore, four of the species diagnostic for Zone III (*Globorotalia fohsi* zone) were also present in the Barbados samples, namely,

*Bulimina illingi* Cushman and Stainforth
*Globigerina* cf. *digitata* H. B. Brady
*Globorotalia canariensis* (d'Orbigny) (large form)
*Globorotalia fohsi* Cushman and Ellisor

Many of the Foraminifera described from Eocene marls of Cuba (1, 8, 44) are also present in the Cipero faunas, but samples donated to the Trinidad Leaseholds collections by Mrs. D. K. Palmer reveal that, though the Trinidadian and Cuban faunas are homeotopic, they differ in age. The Cuban marl assemblages contain such Eocene Foraminifera as *Hantkenina* spp. and pustulose *Globorotalia*. It seems from the available literature that the Oligocene of Cuba is comparable rather with the San Fernando formation of Trinidad than with the Cipero. It may be noted, however, that the pelagic species *Globorotalia fohsi* was recorded by Palmer (42) in the Cojimar formation and furthermore that with one exception samples containing this species did not contain *Globorotalia menardii* or *Sphaerodinella dehiscens*. It would appear from this that the Cojimar formation of Cuba corresponds jointly in age with Zone III (*Globorotalia fohsi* zone) of the Cipero formation and the overlying *Globorotalia menardii* zone of the Lengua member in Trinidad.

Except for similar age correlations with this last, based on the evidence of pelagic species, the Cipero faunas show little in common with other Oligocene deposits described in tropical America. The regional correlation of the Cipero formation will become much clearer when the Brasso and San Fernando formations have been fully described and their faunas compared with their many homeotopes.

Palmer (42) remarked on the presence in the Cuban Oligocene of foraminiferal species only known in the youngest deposits of the Indo-Pacific region, for example, the Pliocene of Kar Nicobar, after Schwager. Cushman and Stainforth (13) observed the same feature in the Cipero faunas, in which *Annulopatellina advena*, for instance, belongs to a genus previously recorded only in Recent Australasian faunas.

REFERENCES


1. BERMUDEZ, P. J., "Nuevas especies de foraminiferos del Eoceno de Cuba," *Mem. Soc. Cubana Hist. Nat.*, Vols. 11, 12 (1937, 1938).
2. BRADY, H. B., *Reports on the Scientific Results of the Voyage of H.M.S. Challenger During the Years 1873–76. Zoology*, Vol. 9. London (1884).
3. COLLINS, R. L., "American Tertiary Pteropod Mollusks," *Johns Hopkins Univ. Studies in Geology*, No. 11 (1928).
4. CUNNINGHAM-CRAIG, E. H., "The Geological Structure of Trinidad: a Popular Lecture Founded on Recent Investigations, *Victoria Institute Pamphlet*. Port of Spain (1905).
5. ———, "The San Fernando Manjak Field. Report by the Government Geologist," *Council Paper 3*. Port of Spain (1905).
6. ———, "Trinidad Oilfields. General Report by the Government Geologist on the Central and Northern Anticlines (Western District)," *Council Paper 60*. Port of Spain (1907).
7. CUSHMAN, J. A., "*Cycloculina* in the Western Hemisphere," *Contrib. Cushman Lab. Foram. Research*, Vol. 5, No. 1 (1929), pp. 4, 5.
8. CUSHMAN, J. A., AND BERMUDEZ, P. J., "New Genera and Species of Foraminifera from the Eocene of Cuba," *ibid.*, Vol. 12 (1936), pp. 27–38; 55–63; Vol. 11 (1937), pp. 1–29, 106–10.
9. CUSHMAN, J. A., AND JARVIS, P. W., "New Foraminifera from Trinidad," *ibid.*, Vol. 5, No. 1 (1929), pp. 6–17.
10. ———, "Some Interesting New Uniserial Foraminifera from Trinidad," *ibid.*, Vol. 10, No. 3 (1934), pp. 71–75.
11. CUSHMAN, J. A., AND OZAWA, Y., "A Monograph on the Foraminiferal Family Polymorphinidae, Recent and Fossil," *Proc. U. S. Nat. Mus.*, Vol. 77 (1930).
12. CUSHMAN, J. A., AND PARKER, F. L., "Some American Eocene Buliminas," *Contrib. Cushman Lab. Foram. Research*, Vol. 12 (1936), pp. 39–45.
13. CUSHMAN, J. A., AND STAINFORTH, R. M., "The Foraminifera of the Cipero Marl Formation of Trinidad, British West Indies," *Cushman Lab. Foram. Research Spec. Pub. 14* (1945).
14. DUNCAN, P. M., "On the Fossil Corals (Madreporia) of the West Indian Islands," *Quar. Jour. Geol. Soc.*, Vol. 24. London (1867).
15. FRANKLIN, E. S., "Microfauna from the Carapita Formation of Venezuela," *Jour. Paleon.*, Vol. 18 (1944), pp. 301–19.
16. GALLOWAY, J. J., AND HEMINGWAY, C. E., "The Tertiary Foraminifera of Porto Rico," *Scientific Survey of Porto Rico and the Virgin Islands*, New York Acad. Sci., Vol. 3, Pt. 4 (1941)
17. GEOLOGICAL SOCIETY OF AMERICA, "Classification and Nomenclature of Rock Units," *Bull. Geol. Soc. America*, Vol. 44 (1933).
18. GUPPY R. J. L. For general reference to Guppy's less accessible papers see the reprint edited by G. D. HARRIS in *Bulls. Amer. Paleon.*, Vol. 8, No. 35 (1921).
19. ———, "On the Relations of the Tertiary Formations of the West Indies," *Quar. Jour. Geol. Soc. London*, Vol. 22 (1866).
20. ———, "Notes on West Indian Geology, with Remarks on the Existence of an Atlantis in the Early Tertiary Period, and Description of Some New Fossils from the Caribbean Miocene," *Geol. Mag.*, Vol. 4 (1867).
21. ———, "On the Tertiary Fossils of the West Indies with Especial Reference to the Classification of the Kainozoic Rocks of Trinidad," *Proc. Sci. Assn. Trinidad*, Pt. 3 (1867).
22. ———, "West Indian Tertiary Fossils," *Geol. Mag.* (September-October, 1874).
23. ———, "Polycistina Beds of South Naparima," *Agricultural Record*, Vol. 3. Trinidad (1890).
24. ———, "The Tertiary Microzoic Formations of Trinidad," *Quar. Jour. Geol. Soc. London*, Vol. 48 (1892).
25. ———, "Radiolarian Marls of South Naparima," *Jour. Trinidad Field Nat. Club* (December, 1893).
26. HARRISON, J. B., AND JUKES-BROWN, A. J., "The Oceanic Deposits of Trinidad, British West Indies," *Quar. Jour. Geol. Soc. London*, Vol. 55 (1899).
27. HEDBERG, H. D., "Foraminifera of the Middle Tertiary Carapita Formation of North-Eastern Venezuela," *Jour. Paleon.*, Vol. 11 (1937), pp. 661–97.
28. HEDBERG, H. D., AND PYRE, A., "Stratigraphy of North-Eastern Anzoategui, Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28 (1944), pp. 1–28.
29. ILLING, V. C., "Geology of the Naparima Region of Trinidad, British West Indies," *Quar. Jour. Geol. Soc. London*, Vol. 84 (1928).
30. KEEN, A. M., "Catalogue and Revision of the Gastropod Sub-Family Typhininae," *Jour. Paleon.*, Vol. 18 (1944), pp. 50–72.
31. KUGLER, H. G., "Summary Digest of the Geology of Trinidad," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 20, No. 11 (1936).

32. ———, "The Eocene of the Soldado Rock near Trinidad," *Bol. de Geol. y Min.*, Tomo 2, Nos, 2, 3, 4. Caracas (1938).
33. ———, Stratigraphic Chart, in Vaughan and Cole (55, pp. 4, 5). Dated 1939, published 1941.
34. LEHNER, E., "Introduction a le géologie de Trinidad," *Annales de l'Office Nationale des Combustibles Liquides.* Paris (1935).
35. LIDDLE, R. A., *The Geology of Venezuela and Trinidad.* Fort Worth, Texas (1928).
36. MAURY, C. J., "The Soldado Rock Type Section of Eocene," *Jour. Geology*, Vol. 37 (1929).
37. ———, "The Soldado Rock Section," *Science*, Vol. 82, No. 2122 (1935).
38. NATLAND, M. L., "The Temperature- and Depth-Distribution of Some Recent and Fossil Foraminifera in the Southern Californian Region," *Bull. Scripps Inst.*, Tech. Ser., Vol. 3, No. 10 (1933).
39. NORTON, R. D., "Ecologic Relations of Some Foraminifera," *ibid.*, Vol. 2, No. 9 (1930).
40. NUTTALL, W. L. F., "Tertiary Foraminifera from the Naparima Region of Trinidad," *Quar. Jour. Geol. Soc. London*, Vol. 84 (1928).
41. ———, "Lower Oligocene Foraminifera from Mexico," *Jour. Paleon.*, Vol. 6 (1932), pp. 3–35.
42. PALMER, D. K., "Foraminifera from the Upper Oligocene Cojimar Formation of Cuba," *Mem. Soc. Cubana Hist. Nat.*, Vols. 14, 15 (1940–1941).
43. PALMER, D. K., AND BERMUDEZ, P. J., "An Oligocene Foraminiferal Fauna from Cuba," *ibid.*, Vol. 10, No. 4 (1936).
44. PARKER, F. L., AND BERMUDEZ, P. J., "Eocene Species of the Genera *Bulimina* and *Buliminella* from Cuba," *Jour. Paleon.*, Vol. 11 (1937), pp. 413–16.
45. RENZ, H. H., "Stratigraphy of Northern South America, Trinidad, and Barbados," *Proc. 8th Amer. Sci. Congr.*, Vol. 4 (1942), pp. 513–71.
46. ROHR, K., "Orientated Hand-Coring in Geological Field-Work," *Jour. Inst. Petroleum*, Vol. 30, No. 244 (1944).
47. RUTSCH, R., "Pteropoden und Heteropoden aus dem Miocaen von Trinidad (Britisch Westindien)," *Eclogae Geol. Helvetiae*, Vol. 27, No. 2 (1934).
48. SCHILDER, F. A., "Cypraeacea aus dem Tertiär von Trinidad, Venezuela und Antillen," *Abh. Schweizer. Paleon. Gesell.*, Bd. 62 (1939).
49. SENN, A., "Die stratigraphische Verbreitung der tertiaren Orbitoiden," *Eclogae Geol. Helvetiae*, Vol. 28, No. 1 (1935).
49-a. ———, "Paleogene of Barbados and Its Bearing on History and Structure of Antillean-Caribbean Region," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24 (1940), pp. 1548–1610.
50. SVERDRUP, H. U., JOHNSON, M. W., AND FLEMING, R. H., *The Oceans.* Prentice-Hall Inc., New York (1942).
51. THOMAS, M. L., "Oil Prospecting on the North Coast of Venezuela," *Oil Engineering and Finance* (June, 1924). London.
52. THORP, E. M., "Descriptions of Some Sea-Bottom Samples from the Western North Atlantic and the Caribbean Sea," *Bull. Scripps Inst.*, Tech. Ser., Vol. 3, No. 1 (1931).
53. VAUGHAN, T. W., "Criteria and Status of Correlation and Classification of Tertiary Deposits," *Bull. Geol. Soc. America*, Vol. 35, No. 4 (1924).
54. ———, "On the Relative Value of Species of Smaller Foraminifera for the Recognition of Stratigraphic Zones," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7, No. 5 (1923).
55. VAUGHAN, T. W., AND HOFFMEISTER, J. E., "Miocene Corals from Trinidad," *Papers from Dept. of Marine Biology, Carnegie Inst.*, Vol. 23 (1926).
56. VAUGHAN, T. W., AND COLE, W. S., "Preliminary Report on the Cretaceous and Tertiary Large Foraminifera of Trinidad, B.W.I.," *Geol. Soc. America Spec. Paper 30* (1941).
57. WALL, G. P., AND SAWKINS, J. G., *Report on the Geology of Trinidad.* London (1860).
58. WARING, G. A., "The Geology of the Island of Trinidad, B.W.I." *Johns Hopkins Univ. Studies in Geology*, No. 7 (1926).
59. WILSON, C. C., "The Los Bajos Fault of South Trinidad," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 12 (1940).
60. VAN WINKLE, K., "New and Otherwise Interesting Tertiary Molluscan Species from the East Coast of America," *Bulls. Amer. Paleontology*, Vol. 8, No. 33, p. 19.
61. WOOLNOUGH, W. G., "Geological Extrapolation and Pseudo-Abyssal Sediments," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 5 (1942).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1331-1339, 9 FIGS.

# ISOPACHOUS MAPS OF SAND RESERVOIRS[1]

JAY B. WHARTON, JR.[2]
Lafayette, Louisiana

## ABSTRACT

The methods are outlined for the construction of isopachous reservoir maps as a preliminary to the determination of hydrocarbon reservoir volumes. This application, though in common use, has seldom been described or figured in publications.

## INTRODUCTION

Isopachous maps have long been employed by geologists to depict the volumetric persistence of lithologic units, or have been used as the basis for studies of structural growth. Ordinarily where an isopachous map has been employed to map an individual sand, the contours are drawn through points of equal thickness and left dangling either at the edge of the mapped area or where no control was available.

The maps considered here are of a different type. Since the lateral extent of that portion of the reservoir carrying hydrocarbons is usually known, isopachous contours thereon will close within the mapped area. Further, as is seldom the case in subsurface mapping, the contours may have sharp angles along their courses instead of continuous smooth curves throughout.

An isopachous map based on the net effective saturated sand thickness of a hydrocarbon reservoir is a two-dimensional presentation of the three-dimensional effective oil sand body present below the surface. The volume of this solid is ordinarily determined by measuring with a planimeter the area enclosed by each contour and multiplying these areas by the contour interval. The area enclosed by the zero contour is multiplied by only half of the contour interval. The sum of these increments is in turn multiplied by a suitable recovery factor per unit volume, which will then give a figure for producible hydrocarbons originally in place within the reservoir. While several alternate methods are often employed to obtain reservoir volume from such maps, the writer finds this the quickest and simplest. All are of adequate accuracy in view of the nature of the data and the application of the resultant.

Naturally such computations are of great economic importance to the company developing any field, and the maps from which they are derived are of such value that examples of them are seldom found in the published literature. One of the few published examples of this type of map is illustrated in an article on the Benton field, Louisiana.[3] This study describes the detailed research which

[1] Manuscript received, April 9, 1948.

[2] Consulting geologist with Bates and Cornell. The writer wishes to thank the members of this firm for helpful criticism and suggestions throughout the preparation of this manuscript, and Mrs. Wharton who drafted the figures.

[3] W. L. Horner and E. G. Trostel, "Benton Field Unit," *Oil and Gas Jour.* (March 4, 1948), pp. 77–85.

may be necessary in determining reservoir volumes and distribution of the hydrocarbons in the reservoir. The use of such maps accurately prepared is imperative in determining the fractions of a unitized field which are to be allocated to the various interests represented.

For the preparation of this type of map, it is normally prerequisite that the field being studied should be nearing complete development, well spacing should not be too wide, and a majority of the wells should have completely penetrated the subject reservoir. It is assumed that an electrical or other type log has been made of each well and the reservoir cored to determine content, contacts, and so forth. How thoroughly each of these suggested requirements need be met will vary from field to field. In general, the more completely they are fulfilled, the more reliable will be the results.

## BASIC DATA

It will be necessary to have at hand structure maps drawn not only on the top of the sand but also on its base. It will be found helpful to prepare a tabulated data sheet showing the amounts of net gas, oil, and water sand present in each well together with the top and base of the sand corrected for differences in elevation.

In many instances the sand being mapped may have different percentages of its thickness made up of interbedded shale members or impervious streaks. As the isopachous map is to be drawn on net effective sand only, it is necessary that such shale or other non-producible portions of the sand be subtracted before the sand thickness data are used on the map.

Figure 1 shows a part of an electrical log with a reservoir sand divided into its component parts of oil and water after the non-producible parts have been deducted. The log shows two tight streaks in the sand, probably shale members. Considerable care should be exercised in the determination of what portions of the sand are truly effective between the top and base of the sand reservoir. The logs should be carefully checked against pertinent core records which may be available. In addition to determining the amounts of shale present, sand-core porosities and permeabilities, if available, should be considered. For example, in one field now being unitized it was mutually agreed that any sand with less than 10 millidarcys permeability be regarded as not effective.

## PROCEDURE

For clarity, relatively simple reservoir data have been employed in preparing the illustrative figures. A hypothetical field is used here for demonstration. The same set of wells and data form the basis for the maps illustrated in Figures 2, 5, 7, and 8. It should be noted that this method is applicable to any hydrocarbon sand reservoir, except that in sands carrying gas-distillate only the well spacing is usually too wide to justify this detailed a method.

The following outline applied to a single-phase reservoir, such as an oil sand.

1. After net sand values have been determined for all the wells in or adjacent to the field, draw an isopachous map on total net sand (oil and water sand combined). This map should include all the field wells and all dry holes adjacent to

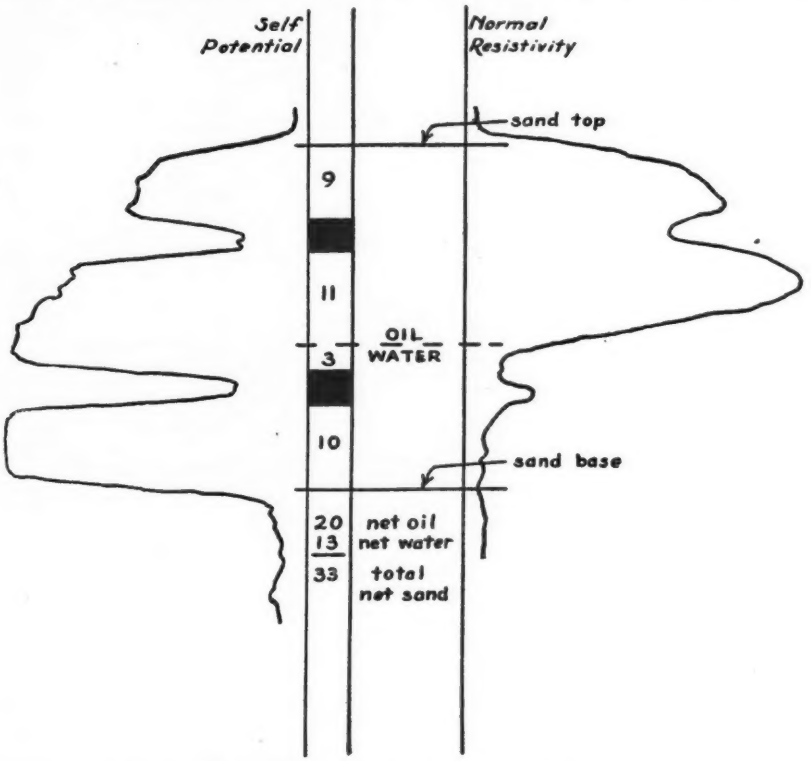



FIG. 1.—Idealized electrical log showing one method of determining net sand thickness.

the field, and since it is not concerned with the content of the sand, the resultant is an ordinary regional isopachous map. Dry holes will contribute as strongly as producers to the configuration of this map. Neglecting to consider adjacent dry holes in the preparation of reservoir net sand maps is one of the major sources of error in their construction. A total net sand map for the hypothetical field is shown in Figure 2.

2. Reference to the field structure map, as conventionally prepared, will give the outer limits of the oil reservoir. This is given by the contour on the struc-

ture map which follows the intersection of the field water level and the top of the sand, or the oil-water contact. Trace this contour onto a blank field map and label it "zero" as it will be the line of zero oil-sand thickness.

3. Next, trace onto this blank map the intersection of the water level and the base of the sand. To obtain this it may be necessary to draw a structure map on

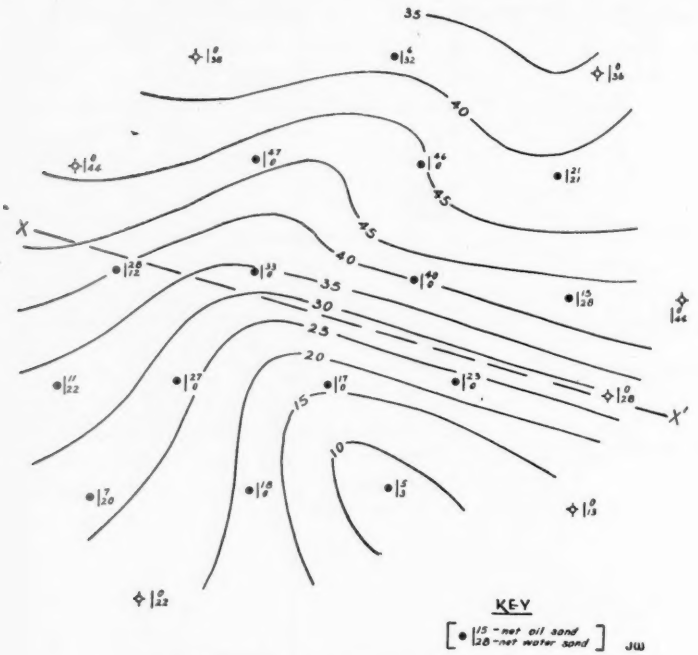



FIG. 2.—Isopachous map drawn on total net sand.

the sand base. Preparation of such a map will be time well spent when large reserves of oil are involved and sample data are available. This intersection should be traced off as a dashed line to prevent confusion with contours.

The map now has two concentric, probably very irregular, closed lines, the outer one solid, the inner one dashed. Presumably all wells drilled within the dashed line will find the sand carrying oil only. In the area between the dashed and solid lines (the so-called oil-water wedge) wells will find the upper part of the sand carrying oil, the lower part carrying water. Outside the solid line only water will be found, as illustrated in Figure 3.

As the total net sand and the net oil-sand data for wells inside the dashed line are identical, the total net sand contours and the final net oil-sand isopachous

contours should be identical in this area. Superimpose the blank map over the total net sand map previously prepared and trace off all contours that lie inside the dashed line. The most important part of the final isopach is now complete. It should be noted here that additional complications are introduced when a gas

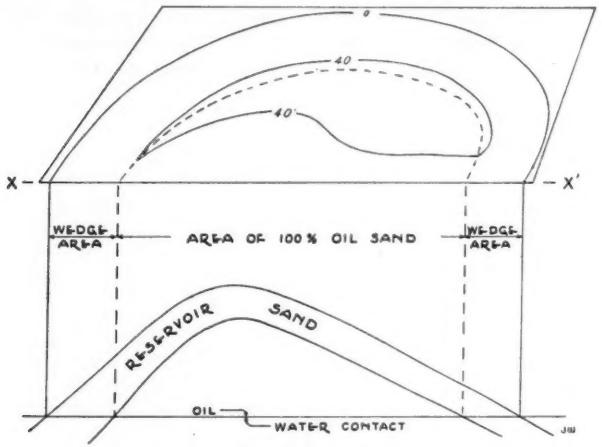



FIG. 3.—Cross section along $XX'$ from Figure 2.

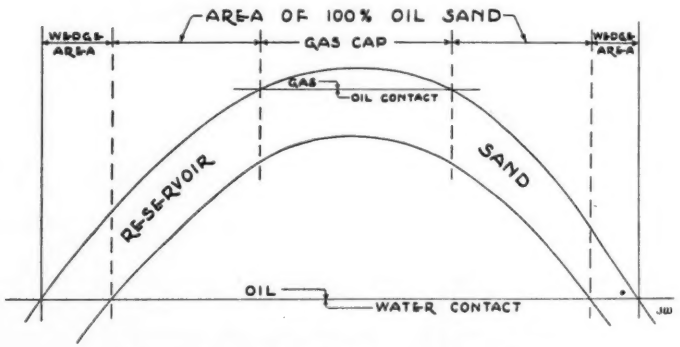



FIG. 4.—Cross section of an oil reservoir with gas cap.

cap is present. The total net sand contours may be used only in those areas where the reservoir is single phase, or entirely oil, as in Figure 4. Should the reservoir be so shaped that in some parts of the field the entire thickness of the sand is in the gas cap, here too the total net sand contours should be used.

4. Left to be contoured is the oil-water wedge, which has been done in Figure 5. Whereas in the central part of the isopach, the total thickness of the sand

determines the configuration of the contours, in the wedge the major influence on contours is the structural attitude of the sand, though the total thickness still has effect.

As a result of structural influence the isopachous contours in the wedge will more or less parallel the structure contours of the same area. It will be seen that where a contour crosses the dashed line it makes an abrupt turn, which turn will be towards the next numerically larger contour. Contour intervals used on reservior isopachs should be as small as the data will support. While 5- and 10-foot

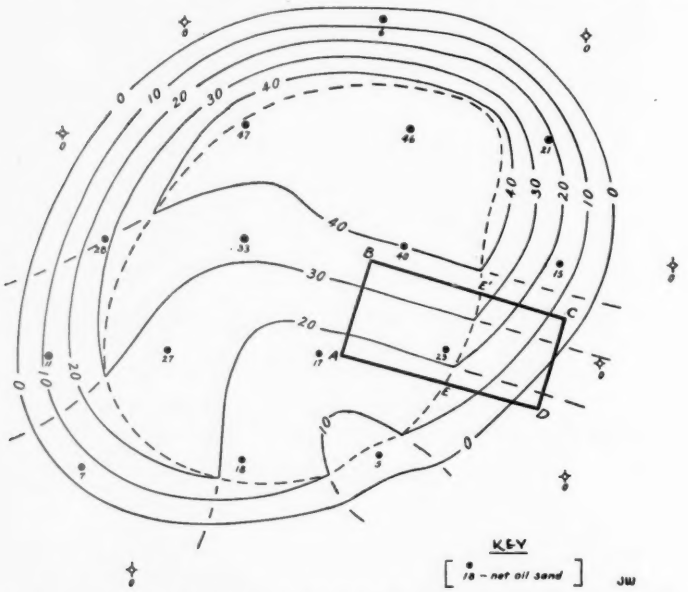



FIG. 5.—Isopachous map of net oil sand with dashed lines showing location of total net sand contours. Inner edge of oil-water wedge shown by dashed closure.

contour intervals have been used here for clarity, 2-foot or even 1-foot intervals would be more advisable.

After the wedge is contoured, planimetering will be somewhat facilitated by the removal of the dashed line. Figure 6 shows a sand segment *ABCD* taken from Figure 5 through which passes the heavily shaded water table (oil-water contact plane). The diagram is self-explanatory showing block *ABE'E* to be a segment of a total net sand map with structure having no influence, while the block *CDEE'* has been altered by the water table to become a segment of a cone and is contoured as such.

Figure 7 shows the final isopachous map with the dashed line removed.

In summary the four steps involved are:

1. Determine net sand totals for each well and draw a regional isopach on these data.

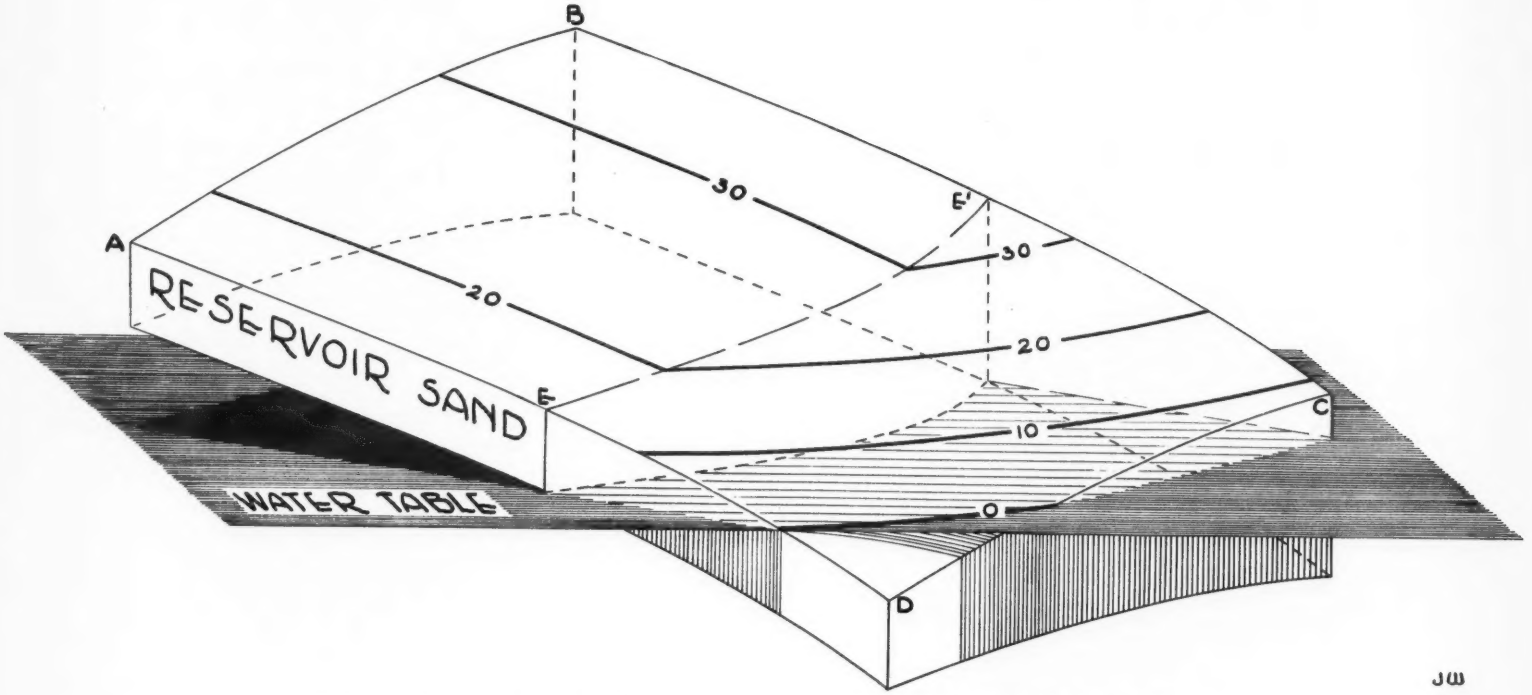



FIG. 6.—Block diagram of area *ABCD* from Figure 5 showing influence of water table on thickness contours.

FIG. 7.—Completed isopachous map of oil reservoir.

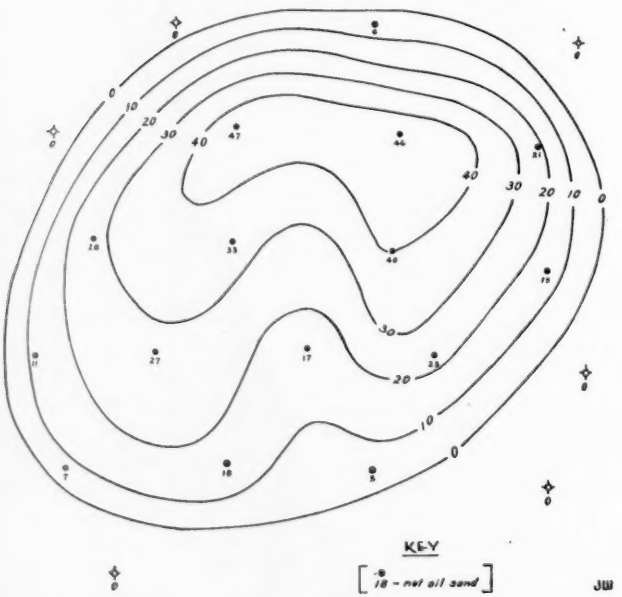



FIG. 8.—Isopachous map drawn on net oil-sand data *only*. Data taken from Figure 5.

2. Trace on to blank map the oil-water contact for top and base of sand from the structure maps.

3. Trace isopach contours from No. 1 on blank map inside base sand oil-water contact.

4. Contour oil-water wedge more or less paralleling structure contours to fit data from wells in the wedge.

To show the errors which can occur when *only* net oil sand is considered, Figure 8 has been prepared from the data on Figure 5. To make comparison more direct, the 40-foot contours from Figures 7 and 8 have been placed side by side for inspection in Figure 9. Planimetering these two irregular figures, it is found that area "Y" is 1.8 times as large as area "Z." The total reservoir volume determined from Figure 7 is 1.1 times as large as that from Figure 8.

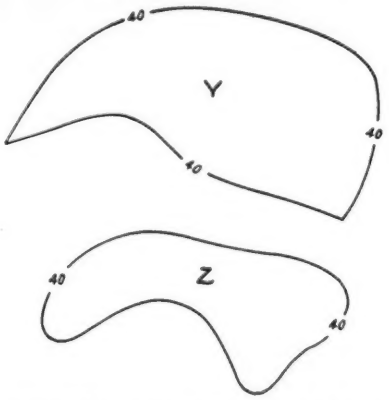



FIG. 9.—Comparison of areas resulting from two mapping methods. Area "Y" from Figure 7 is 1.8 times as large as area "Z" from Figure 8.

## CONCLUSION

The example used in this paper for demonstration purposes is "text-book" simple. Any geologist who has worked with reservoir problems probably feels that, while such a field may exist, it has never been his good fortune to work with it. Most fields manage to complicate the problem in some way. The sand may be highly faulted, truncated by a salt dome, have a gas cap or possibly a large shale member through its center. In the latter case much the safest method would be to consider the two sand sections separately. Whatever the difficulties, it is the purpose of this paper to point out that a total net sand map is a very valuable tool in the preparation of the final isopachous map. It is not only vital within the area where the reservoir is single-phase, but is also an aid in contouring within the area of oil-water wedge or even when the sand has its lower part in the water throughout the field.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1340-1348

# SOME NOTES ON GEOLOGY AND GEOLOGISTS, 1907–1947[1]

HUGH D. MISER[2]
Washington, D. C.

The 40-year period 1907–1947 covered in this address begins in the year that I embarked on the career of a geologist. My purpose at this time is neither to give an autobiography nor sketch the careers of any fellow geologists, even in summary fashion. It is to state briefly some observations on the progress and trends of American geology and geologists as I view the 40 years just past and also attempt to view the future.

The period here discussed does not fall within or overlap the first 100 years of American geology. The first century was notable for its broad-minded distinguished leadership and for important scientific discoveries, substantial progress, and wise planning for the future. The 40-year period does, however, cover one of the most important periods in our science. It spans World Wars I and II; it saw the ranks of professional geologists in our country increase from possibly 500 to about 10,000; it witnessed an outstanding development and formation of numerous geological societies; it was characterized by tremendous advancements in scientific knowledge and useful service; and it saw wide recognition and acceptance of geology as a useful and cultural science.

The increasing interest in geology and the expanding fields of the geologist are clearly illustrated by the founding of new geological societies and the increases in membership of both the newer and older societies. The national societies formed since 1907 together with their dates of organization are:

1908—Association of American State Geologists; successor of Mississippi Valley Association of State Geologists organized in 1906.
1908—Paleontological Society.
1910—Seismological Society of America.
1917—Southwestern Association of Petroleum Geologists; in 1918 name changed to American Association of Petroleum Geologists.
1919—American Geophysical Union.
1919—Mineralogical Society of America.
1920—Society of Economic Geologists.
1927—Society of Economic Paleontologists and Mineralogists.
1930—Society of Petroleum Geophysicists; in 1936 name changed to Society of Exploration Geophysicists.
1940—Society of Vertebrate Paleontology.

At present the American Geological Institute is in process of organization and a proposed constitution is being considered by eleven national societies.

Of our numerous geological societies the American Association of Petroleum Geologists, having 5,519 members, is the largest in the world. The growth of the membership of the Association has been phenomenal. It reflects the increase in

[1] Published by permission of the director of the United States Geological Survey. This paper was presented in 1948 at the Ohio State University, Northwestern University, and University of Illinois, and before Shawnee, Tulsa, and Oklahoma City geological societies.

[2] Geologist, United States Geological Survey.

oil-exploratory activity both in the United States and abroad. Some membership statistics by decades from 1917 to 1947 are:

| | | |
|---|---|---|
| In 1917 | 94 members lived in United States | |
| In 1927 | 1,540 members lived in United States | 130 members lived in other countries |
| In 1937 | 2,078 members lived in United States | 263 members lived in other countries |
| In 1947 | 4,548 members lived in United States | 496 members lived in other countries |

The states having the most oil geologists are the ones that have the greatest oil production and their geologists are increasing in number in relation to the quantity of oil produced. In March, 1947, the members of the American Association of Petroleum Geologists living in the five leading oil-producing states (Texas, California, Oklahoma, Louisiana, and Kansas) totaled about 3,280. Quantitatively expressed those states had one geologist for each 450,000 barrels of oil produced in 1946. By comparison they had one geologist for each 600,000 barrels of oil produced in 1937.

The growth of the Geological Society of America from 1907 to 1947 was gigantic in membership, resources, and responsibilities. The membership increased from 294 (263 United States; 31 other countries) to 1,053 (933 United States; 120 other countries), and the resources grew to about $5,500,000 chiefly as the result of the Penrose Endowment Fund. These resources are probably adequate for the actual needs of the society for an indefinite period and they provide means for encouragement of otherwise ill supported investigation and publication. The approbation of all geologists is due the society for the quality and quantity of its reports. But I am certain that I am only one of many who have neither book shelves nor space to house all of them. No longer do we hear protestations from some fellows who some years ago felt that they were not receiving enough printed pages for their annual dues of $10.

In 1946 the Geological Society of America which had long had a Cordilleran section added a new section, the Section on Engineering Geology, and in 1947 it added another, the Rocky Mountain Section. These sections represent a small fraction of the ever increasing number of local and regional groups to be found throughout the United States. Three such groups are recognized as sections of the American Association of Petroleum Geologists and a total of twenty-five societies are affiliated with that Association. In addition many societies are independent and are not connected with national organizations.

Many local groups are composed of members of diversified interests and the rolls of some of them are composed altogether of specialists in some particular field or branch of the science. As illustrative of the typical diversity of these local groups I may cite the ones in Washington, D. C.

Geological Society of Washington founded in 1893
Pick and Hammer Club founded in 1894
Petrologists Club founded in 1910
Paleontological Society founded in 1934

In addition the geologists of Washington have the opportunity to join the Washington Academy of Sciences and fully a dozen other societies.

A large proportion of the local groups, as well as all the national societies, support serials or special reports in which are printed the scientific contributions of their members. Meetings are held annually or more frequently for the presentation of papers and discussion. In addition, field conferences are sponsored. These have increased in number and in attendance, in response to the keen, active, and broad interests of our geologists and their desire for collaboration, a common solution of problems, and the exchange of ideas. Certainly the best place to reach a common understanding is a rock outcrop instead of an office, class room, correspondence, or printed discussion. Among the notable well planned field conferences are those of the Kansas Geological Society which has sponsored fifteen annual conferences, each equipped with elaborate guidebooks to different areas in the mid-Continent region, the Black Hills, and the Front Range of the Rockies. Field conferences of American geologists during World War II were necessarily restricted in number or discontinued. But with the end of the war the pent-up hunger for conferences broke loose and a record number of conferences have been organized and conducted in all parts of the country. Furthermore, 1947 saw previous attendance records surpassed in three or more conferences. One of these was the Tulsa Geological Society's trip in May to the Ouachita Mountains of Oklahoma, attended by 224 geologists and oil men. Another was a trip in the Bighorn Basin in August, attended by about 280 geologists. It followed the inaugural meeting of the Rocky Mountain section of the Geological Society of America and was conducted under the joint auspices of the Wyoming Geological Association, the University of Wyoming, and the Yellowstone-Bighorn Research Association. A third field conference was the annual Tri-State Geologic Field Conference which was held in the fall in Wisconsin. This conference comprises the departments of geology, graduate students, and undergraduate majors of the universities and colleges of Illinois, Wisconsin, and Iowa, and also the State surveys. The attendance was almost 300.

The growing interest in rocks and minerals is attested by the growing number of persons who have adopted the hobby of collecting gems and minerals and who have organized numerous local mineral and gem societies to increase their knowledge of minerals. Many private collections of minerals are remarkable for their beautiful and rare specimens, and their acquisition represents a lifetime of effort. In addition the mineral stands of roadside dealers attract the person who visits our mining districts.

In the words of James D. Dana,

> Geology is eminently an out-door science; for strata, rivers, oceans, mountains, valleys, volcanoes, cannot be taken into a class room. . . . Field work . . . makes the facts in the science real. It also teaches with emphasis the great lesson that existing forces and operations are in kind the same that have formed the rocks, the valleys, and the mountains.

These words and others in Dana's textbook, *The Geological Story* (1895) introduced geology to me in 1901 while I was a high-school student at Pea Ridge, Arkansas.

In the ensuing years there glow brighter the memories of my enthusiastic and inspiring science teachers of high school and college days. They were men of strong character and their enthusiasm was kindled by their search for truth. Such teachers are found in numerous institutions, both small and large, in all parts of our land. They are our assurance for future leadership and progress in our science. The load and responsibilities of these worthy teachers could be carried more easily if their ranks were joined by others equally competent. This recruitment of additional competent teachers is a grave problem, for eminent science teachers are too few.

The education of geologists has appropriately been the subject of spirited and enthusiastic conferences in recent years in connection with the meetings of various geological organizations. The printed records of the discussions and papers have been published in the *Interim Proceedings* of the Geological Society of America.

Some philosophical *do's*, *don'ts*, and *musts* received in school days have lived with me to the present. They are here repeated:

1. Each geologist must be honest with himself in the use of facts; he must make certain that his facts are truly facts.
2. Anything worth doing is worth doing well; do your best always; do not guess.
3. Do not worry about the future; do each day's work well and happily; if you do the morrows will take care of themselves, for each in turn will become to-day, one at a time.
4. If something can be done to-day, do not postpone it until to-morrow.
5. If a job can be finished in one day, do not take two days.
6. If something can be said in two words, do not use three words.
7. A writer must stick to his subject.
8. Ability to write well requires work including concentration and logical thinking; conversely, inability to write indicates inability to think and concentrate; thus poor writing denotes inability of author to work when he attempts to write.
9. The incentive of a geologist should be love for his work and should not be salary which is in reality a means to attain ambition's goal. This last philosophy may be labeled old-fashioned by some. But do not Americans in general love to work for the satisfaction and enjoyment they receive as rewards for making and growing useful things?

An increasing volume of geological knowledge has flowed from the presses in the past 40 years in the form of papers, reports, and maps. Their listing and a review of their contents would be too long and time-consuming to be attempted in the present address. It does, however, seem wise to mention some of the milestones in the progress of geology in our country. These include:

Geologic map of the United States published in 1932 by the United States Geological Survey.

Three geologic maps of North America. The first published in 1906 for the 10th International Geological Congress; the second printed in 1912 by the United States Geological Survey; and the third printed in 1946 by the Geological Society of America.

Glacial map of North America published in 1945 by the Geological Society of America.

Tectonic map of the United States published in 1944 by the American Association of Petroleum Geologists.

Geologic maps of some 39 States; some published by State geological surveys; some by local geological societies; and some by United States Geological Survey.

Bibliographies of geologic literature published by the United States Geological Survey, Geological Society of America, and Society of Economic Geologists.

Lexicon of geologic names by M. Grace Wilmarth (*United States Geological Survey Bulletin 896*).

United States Geological Survey's 227 folios of the geologic atlas of the United States. A new series of maps comparable with those of the folios is being planned by the Survey.

Many maps and reports represent the combined efforts of different agencies

and organizations. With the passing of the years cooperation in joint enterprises of broad, regional, and national scope has increased notably. The tectonic map of the United States, and fully 17 State geologic maps, are outstanding illustrations of such cooperation. Beginning with the Oklahoma geologic map published in 1926 many State geologic maps have been prepared with the collaboration of oil companies and the mining industry which have supplied a tremendous amount of information. Besides the Oklahoma map such maps include those of Colorado (1935), Texas (1937), Kansas (1937), California (1938), Mississippi (1945), Montana (1945), and Louisiana (1946).

As illustrative of projects of general interest where cooperation is essential to achieve the best results there may be cited the project, now in progress, for the preparation of a rock-color chart. This is being prepared by a committee composed of representatives of the Geological Society of America, American Association of Petroleum Geologists, Society of Economic Geologists, Association of American State Geologists, and United States Geological Survey. This chart will be of much value and help to all geologists who work with rocks in the field and in the laboratory.

The wide and general acclaim by the public of the present high position of science in our everyday lives and in the affairs of State has never heretofore been equaled in human history. This position of responsibility and usefulness is a trust and heritage that we must treasure, maintain, and enlarge with integrity, energy, and foresight.

Concerning the heavy responsibility of science in the welfare of our people Under Secretary of War Robert P. Patterson made the following significant statement in 1944.

> There is a great voice in the world today, the voice of science and technology. It is a voice heard since ancient times but never until today has it spoken with such authority, have its words been so filled with promise, has it been listened to with such hope. And in no country in the world does the voice speak as eloquently as in our own.
>
> Science and technology have changed and are changing the lives of all men. . . .
>
> It is a heavy assignment of responsibility to say that the future of our country in peace and war is to a great extent in the hands of American scientists in industry, in schools, in universities and government.[3]

As an employee of the United States Government it is appropriate for me to call attention to the widening recognition of the usefulness of geology in the Government service. The strongest kind of evidence for this is the long list of Government agencies that utilize geologically trained personnel. The list, admittedly incomplete, includes:

United States Geological Survey
Bureau of Mines
National Park Service
Reclamation Service
Bureau of Land Management
Oil and Gas Division
Bureau of Plant Industry
Bureau of Foreign and Domestic Commerce

[3] *Industrial Research and National Defense.* A paper presented at the Silver Anniversary Forum on the future of Industrial Research, sponsored by Standard Oil Development Company, the research organization of Standard Oil Company (New Jersey), in New York, October 5, 1944.

Bureau of Standards
Smithsonian Institution
Tennessee Valley Authority
Soil Conservation Service
Atomic Energy Commission
Securities and Exchange Commission
Tariff Commission
Federal Power Commission
Reconstruction Finance Corporation
International Bank
Export-Import Bank of Washington
Office of International Trade Policy
Treasury Department
  Bureau of Internal Revenue
  Division of Tax Research
  Bureau of Federal Supply
Department of National Defense
  Munitions Board
  Research and Development Board
  Industrial College of The Armed Forces
  Army Engineers

The Nation's mineral resources including coal, iron ore, petroleum, natural gas, and many other minerals, in whose discovery and exploration geologists play a leading role, are vital to our industrial civilization, welfare, and national security. The development and utilization of these resources, combined with the other activities of a free aggressive people, have led to an unexcelled standard of living and the high industrial position of the United States. The quantity and quality of our mineral resources are not equaled in any other like area.

Our mineral resources have been utilized through increasing rates of production and the total available quantity of each mineral has been reduced or depleted at corresponding rates. None of this depletion is replenished by the creation by natural processes of new mineral supplies. Thus the Nation's store of minerals is exhaustible. Some of them, such as the important fuels coal, oil, and gas, are completely destroyed in the course of their use, whereas others like iron, copper, and lead may be in part re-used as scrap metal.

Huge quantities of our mineral and other resources were used up during World War II and we are living in a period when one of our problems is the reduction of the deficit in the production of minerals and other things than man needs. The attempt to meet this deficit is causing an unpercedented upward demand on our minerals.

At present some minerals which are so essential to our industrial civilization are so abundant that their supply is for all practical purposes unlimited. Our supplies of other equally essential minerals, also abunant, will sooner or later need to be replenished by the discovery of new deposits or they must be replaced by substitutes. Still others, this country possesses in moderate to very small quantity, and our normal requirements of them must, so far as can now be forecast, continue to be supplied in part from other lands.

The mineral-resource position of the United States has been appraised in several comprehensive reports. The first to be prepared—the Report of the National Conservation Commission (Senate Doc. 676, 60th Congress, 2d Sess.)—was issued in 1909 when conservation of the Nation's mineral resources received the serious consideration of President Theodore Roosevelt. This report contains papers by Geological Survey authors (published also as Geological Survey *Bulletin 394*), who discussed the Nation's resources of coal, petroleum, natural gas, peat, iron ore, gold, silver, copper, lead, zinc, and phosphate deposits.

Another report dealing with 24 commodities was Geological Survey *Bulletin 599*, which was published in 1914.

In 1936 the National Resources Committee issued a comprehensive report, "The Mineral Reserves of the United States and Its Capacity for Production," by K. Leith and D. M. Liddell.

The latest report released in 1947 was prepared by the staffs of the Bureau of Mines and the Geological Survey, "Mineral Position of the United States" in "Investigation of National Resources," *Hearings before a Subcommittee of the Committee on Public Lands*, U. S. Senate, 80th Congress, 1st Sess., May 15, 16, and 20, 1947. It discusses altogether 39 commodities and is the most comprehensive appraisal yet attempted. The estimates of reserves given by qualified experts in the separate chapters on the different commodities are based on such data as are available. They are not to be taken as a measure of the Nation's ultimate mineral wealth, because of the hidden nature of mineral deposits and the consequent incompleteness of information concerning them. In the foreword of the report Secretary of the Interior J. A. Krug fittingly states,

> In general, America's mineral outlook is favorable, but it is obvious that a dynamic program of research and exploration must be pursued if new sources are to be developed to supply future needs.

Guidance in the discovery of these hidden mineral deposits is the responsibility of the geologist with the aid of existing tools such as geophysical prospecting and possibly geochemical prospecting which is being experimented with. The days for the old-time prospector in search for mineral deposits are over. Scientific guidance has been essential for success for many years.

The geologists of the country must increase their efforts to learn more and more concerning the factors and natural processes that control the formation of mineral deposits. They must discover and apply better techniques for forecasting the possible location of hidden mineral deposits. The problems are big, difficult, and complex, but it is axiomatic that the higher the hurdles ahead of us the more energy we must exert to go forward. Such determination and optimism are natural companions, and the reward to date in the discovery of minerals so vital to our country can reasonably be expected to represent in a measure the gauge for the future.

Published geologic maps at a scale that is necessary to guide mineral exploration probably cover less than 10 per cent of the United States. The mapping of the other 90 per cent beginning with the regions offering most promise for mineral exploration is a tremendous job. It will require much resourceful planning, much energy, and many geologists. To accomplish even a considerable part of this task in the next few decades calls for a great acceleration of effort.

More and more drilling under the guidance of geologists, as has been necessary in oil and gas exploration, will be required to discover new mineral deposits.

The search for oil and gas in the United States has made a phenomenal addition to our store of geologic knowledge. The geologic information supplied by the rocks exposed at the surface is only a small fraction of that to be revealed by

the rocks hidden beneath the surface. Altogether $1\frac{1}{4}$ million wells have been drilled for oil and gas in this country and they have reached increasingly greater depths:

In 1898 they passed a mile in depth (5,575 feet).
In 1933 they passed two miles in depth (10,944 feet).
In 1944 they passed three miles in depth (16,246 feet).
In 1947 a well reached a depth of 17,823 feet.

In the words of R. A. Daly at the banquet of the Geological Society of America in Tulsa, Oklahoma, on December 30, 1931, the petroleum industry has contributed the third dimension to geology.

The deep drilling for oil and gas provides stratigraphic and structural information that permits the preparation of many types of maps, both local and regional in character, including those showing structure, thicknesses, and changes in facies of the rocks.

In the addition of the third dimension to geology the drilling for oil has had an unusual opportunity to discover new deposits of other mineral products. Commercially important deposits of other mineral products thus discovered with the advent of deep drilling and search for oil are natural gas, helium, natural carbon dioxide, potash, sulphur, coal, limestone, natural brines, and rock salt.

The storehouse of this vast increase of our geologic knowledge is provided in the records of the wells and the rock samples obtained therefrom. These records include drillers' logs, electric logs, gamma-ray logs, and other types of information. The well records and rock samples provide the geologist with essential data on all types of features of the rocks below the surface. In our exploration for oil, gas, and other minerals for the future the geologist must examine and re-examine time and time again the records and samples with the hope of discovering new data that will provide guidance in future drilling. The necessity for such re-examination of samples is no less important than the necessity for him to return time and time again to re-examine rock exposures at the surface. For this purpose records and samples of numerous wells are filed and preserved by many companies, State geological surveys, and others. This is an invaluable service for the future of geology and mineral exploration. All too often records and samples are destroyed. Ways and means should be found for preserving all of them, for their value is equal to that of gold. Some well samples cost their weight in gold; future use of many will save their weight in gold by preventing the drilling of useless wells; and the use of others will earn their weight in gold by leading to the discovery of new oil.

The present frontiers of the United States include reclamation, conservation, and progress in science and technology. Advances on all of these frontiers are essential for the wise utilization of our soils, forests, streams, and minerals including ground-water. In addition the geologist occupies a wide frontier—the downward search for minerals hidden below the surface. Advances in the tech-

nology of recovery and uses of our minerals and mineral products have resulted in tremendous savings and have thereby increased the supply of our mineral resources. We can not forecast future advances in science and technology, but their record to date inspires confidence for continued progress in these fields.

Reclamation, conservation, and industrial expansion are aflame and glow throughout the land. People everywhere have the will-to-do spirit; our forests and soils are being better utilized; our country is becoming a land of lakes through the harnessing of our numerous streams for power, flood control, and irrigation; and the West, South, East, and North are all building new factories to utilize our widespread, varied, and abundant mineral resources.

The present and the future offer increasing opportunities for the application of geology in mineral exploration and production, in engineering, in economics, and in the use and conservation of our minerals. The present and the future also offer opportunities for geologic leadership in the coordination of different endeavors and sciences. More geologists will be needed in these fields and also in educational insitutions. Increasing vigilance should place in our institutions more and more capable active research geologists of high character and great enthusiasm to train, arouse, and inspire students for leadership.

Initiative and opportunity belong to every citizen of our country, and in consequence thereof each of the some 10,000 American geologists is a research geologist or potential research geologist. Through stimulation and encouragement each geologist should achieve scientific results and publish them for the use of their fellow men and posterity. The duty for the publication of the scientific results of each geologist is no less than the need for him to acquire new knowledge. These goals are attainable through leadership, wise planning, the will to do things, and a lot of hard work.

Geologists will always be confronted with the solution of difficult geologic problems in spite of the ever increasing progress of the science. Whatever their faith and wishes, they will never reach the utopian day when all geologic problems are solved and all geologic facts are known. Some love the science of geology for itself; others love it for the opportunity of applying the science to engineering and economic ends. Geologists who are seeking new knowledge are keyed with hope and optimism; and they are pursuing man's noblest occupation. Their future, like the present, holds work and hope, for the progress of geology and other fields of scientific endeavor means new knowledge, new things, more jobs, and advancement in human welfare.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1349-1355

# GEOLOGICAL NOTES

## CLARIFICATION OF UPPER CAMBRIAN STRATIGRAPHY IN OKLAHOMA[1]

E. A. FREDERICKSON[2]
Norman, Oklahoma

### INTRODUCTION

The recent Cambrian Correlation Chart[3] correctly omits two lithologic units that heretofore have been described and represented in published sections[4] of the Upper Cambrian formations of the Arbuckle and Wichita mountains in Oklahoma. These two units, namely, the so-called "Cap Mountain formation" and the "basal limestone," on the basis of faunal evidence and stratigraphic position, are herein considered to be equivalents of all or portions of the Honey Creek formation.

Although these conclusions were arrived at several years previous to the publication of the Cambrian correlation chart, and were important bases for eliminating the units from the chart, they have heretofore been unpublished, existing only in manuscript form.[5] Sufficient faunal evidence was available prior to publication of the Cambrian correlation chart to substantiate the premise that the "basal limestone" actually represented basal beds of the Honey Creek formation; but the correlation of the so-called "Cap Mountain formation" was based entirely on lithology and on stratigraphic position.

Recent work by W. E. Ham of the Oklahoma Geological Survey in the Mill Creek area of the Arbuckle Mountains has resulted in finding well preserved fossils in leached, dolomitic sandstone lenses of what were heretofore considered

[1] Manuscript received, April 7, 1948.

[2] University of Oklahoma.

[3] B. F. Howell *et al.*, "Correlation of the Cambrian Formations of North America," *Bull. Geol. Soc. America*, Vol. 55, Chart 1.

[4] (a) C. E. Decker, "Progress Report on the Classification of the Timbered Hills and Arbuckle Groups of Rocks, Arbuckle and Wichita Mountains, Oklahoma," *Oklahoma Geol. Survey Cir. 22* (1939), pp. 17–19, 42, 57.
(b) ———, "Contact of Honey Creek and Reagan Formations with Igneous Rocks in Arbuckle and Wichita Mountains, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 7 (1939), pp. 1097–98.
(c) ———, "Two Lower Paleozoic Groups, Arbuckle and Wichita Mountains, Oklahoma," *Bull. Geol. Soc. America*, Vol. 50 (1939), p. 1314.
(d) E. O. Ulrich, "Preliminary Description of the Honey Creek, Fort Sill, Roger and Signal Mountain Formations of Oklahoma," *ibid.*, Vol. 43 (1932), p. 742.
(e) ———, and G. Arthur Cooper, "Ozarkian and Canadian Brachiopoda," *Geol. Soc. America Spec. Paper 13* (1938), Pl. 58.

[5] E. A. Frederickson, *Ph. D. thesis*, University of Wisconsin (1942).

non-fossiliferous dolomites of the so-called "Cap Mountain formation" of Ulrich,[6] which definitely establish the Honey Creek age of this stratum.

The term, "Cap Mountain formation," was first used by Ulrich[7] for the Oklahoma unit in 1932, when he concluded that the Hickory sandstone of Texas corresponded essentially to the Reagan of Oklahoma, and that the Wilberns formation of Texas was equivalent to the Honey Creek formation of Oklahoma, thus indicating that the Cap Mountain formation which is between the Hickory and Wilberns in Texas was "unrepresented in the Oklahoma section except at a single locality on the south side of the Arbuckle Mountains . . . , 10 miles northwest of Tishomingo . . . ." Decker[8] included the so-called "Cap Mountain formation" in the Timbered Hills group on the basis of Ulrich's conclusions. Decker[9] later described the "basal limestone" from an isolated limestone hill in the Wichita Mountains, and placed it at the base of the Upper Cambrian section in that area.

## SO-CALLED "CAP MOUNTAIN FORMATION"

The beds assigned as Cap Mountain equivalents by Ulrich are composed mainly of dolomite and dolomitic limestone and differ lithologically from most of the Honey Creek strata elsewhere exposed.

The dolomitization of these strata apparently destroyed or obscured the trilobite fauna which elsewhere in the mountains is so abundant at this horizon. Fortunately, Ham was able to find a few leached dolomitic sandstone lenses within the dolomites which contained trilobite and brachiopod molds. The fossils occurred at two horizons. At the lower horizon was *Camaraspis convexa*, a diagnostic genus of the Honey Creek *Elvinia* zone. *Billingsella coloradoensis* and *Taenicephalus* sp., which are characteristic genera of the upper Honey Creek *Conaspis* zone, were found at the upper horizon. Thus, the faunal zones of the so-called "Cap Mountain formation" in the Mill Creek area are identical with the Honey Creek formation elsewhere in the Arbuckle and the Wichita mountains. Further justification for discarding the term, Cap Mountain, in this area is found in the stratigraphic position of these strata, that is, between the Reagan sandstone and the Fort Sill formation, exactly the same stratigraphic position occupied by the Honey Creek formation.

Although the so-called "Cap Mountain" beds are dolomites and dolomitic limestones whereas the Honey Creek formation is mainly limestone, excepting in the northwest Wichita Mountain area where abundant sandstone beds are intercalated with the limestones, all are characterized by a high content of glauconite which is typical of Honey Creek lithology.

[6] E. Ulrich, *op. cit.* (1932), p. 742.

[7] *Ibid.*

[8] C. E. Decker, *op. cit.* (1939 a).

[9] C. E. Decker, *op. cit.* (1939 a, b).

Ulrich[10] gives little justification for the extension of the Cap Mountain formation from Texas into Oklahoma, other than the erroneous correlation of the basal Reagan sandstone with the Hickory sandstone, which underlies the Cap Mountain formation in the Central Mineral Region of Texas. Therefore, on the basis of diagnostic faunas and relative stratigraphic position, the so-called "Cap Mountain" beds are considered to be dolomitic Honey Creek equivalents.

### BASAL LIMESTONE

This limestone was described by Decker[11] from one outcrop area of several hundred feet extent on an isolated limestone hill near the south end of Blue Creek Canyon in the Wichita Mountains. The "basal limestone" consists of 98 feet of dense grayish pink limestone, much of it conglomeratic, containing igneous pebbles, and resting unconformably on the pre-Cambrian igneous rock. At the top, this limestone appears to grade into 134 feet of fine-grained, yellowish brown sandstone, which was described as "exceptionally fine-grained Reagan sandstone." This sandstone is overlain by 59 feet of glauconitic Honey Creek limestone.

As previously stated, the "basal limestone" is not a separate unit but represents beds of the lower part of the Honey Creek limestone. Throughout all of the outcrops on the northeast flank of the Wichita Mountains, fine-grained, brown sandstones are present in the Honey Creek formation, and in a well exposed outcrop about 2½ miles south, these sandstones extend through 346 feet of Honey Creek beds. The sandstone above the "basal limestone" is lithologically similar in every respect to these Honey Creek sandstones, but is unlike any of the Reagan sandstones.

Furthermore, when the sandstones at the "basal limestone" locality were traced laterally across a covered area to an outcrop about ¾ mile westward, thin intercalated limestones were found in the upper part of the sandstones, which contained *Pterocephalia sanctisabae*, a common diagnostic genus of the *Elvinia* zone in the lower part of the Honey Creek formation. Also, the Honey Creek limestone beds overlying the sandstone at the type locality for the "basal limestone" contain the *Conaspis* fauna. This is the typical faunal sequence of the Honey Creek formation. Thus, the sandstone unit, which Decker identified as Reagan, is without question part of the Honey Creek formation.

A fossiliferous stratum near the top of the "basal limestone" contains a fauna composed of three genera of trilobites and an abundance of phosphatic brachiopods. The trilobites are three new genera which will be illustrated and described in a forthcoming paper by the writer, and are representative of the basal faunal zone in the Honey Creek formation. These genera, at other localities in the

[10] E. O. Ulrich, *op. cit.*

[11] C. E. Decker, *op. cit.* (1939 b).

Wichita Mountains, have been found with *Pterocephalia*, *Burnetia*, and *Camaraspis*, representative genera of the *Elvinia* zone.

In the light of the foregoing evidence, the writer concludes that the "basal limestone" beds represent the basal beds of the Honey Creek formation. The Reagan sandstone is absent at this locality, and field evidence indicates that the limestone overlapped the Reagan sandstone in this area along the flanks of a small local high of pre-Cambrian igneous rocks.

---

## SUMMARY OF OIL PRODUCTION FROM FRACTURED ROCK RESERVOIRS IN CALIFORNIA[1]

W. S. EGGLESTON[2]
Los Angeles, California

In presenting this summary of oil production from fractured rock reservoirs, no attempt has been made to make an exhaustive review of the individual oil fields involved. To enumerate the many interesting features and individual characteristics of each of the oil fields would require much more time than can now be devoted to this subject.

The main sources of oil production in California are sand reservoirs. In recent years, however, oil production from fractured rock reservoirs has entered the limelight and has gained a certain amount of prominence. Most of the interest has been caused by the occurrence of oil in fractured basement rocks, to some extent a geological anomaly, and not because of oil production from fractured cherts. Production from fractured cherts is not new or in any way unique. Some of the older fields in California have produced most, if not all of their oil, from fractured rock reservoirs. Such fields as Lompoc, Orcutt, and Casmalia, discovered in the years 1903 and 1904, have produced oil for many years from fractured cherts in the Monterey formation of Miocene age.

Fractured rock reservoirs can in general be divided into two groups or classes. This division can be made both as to time of discovery and as to geologic age. The early discoveries made in 1903 and 1904 were in cherts of Miocene age. Recent discoveries have been made in fractured basement rocks probably Jurassic in age.

To illustrate the relative importance of the oil production from fractured rock reservoirs, a survey of the state indicates that approximately 55,000 barrels of oil per day is being produced from such sources compared with approximately 918,000 barrels per day from all of the oil fields in the state. This is equal to 6 per cent of the total oil production from the state.

[1] Read before the Pacific Section of the Association at Los Angeles, November 6, 1947. Manuscrip received, December 8, 1947.

[2] Chief petroleum engineer, Union Oil Company of California.

Of the 55,000 barrels per day produced from these rocks, approximately 15,000 barrels per day is from the so-called "basement rocks," schists and hard altered sandstones. These figures are only an estimate. A calculation of the actual production from fractured "basement rocks" is complicated by multiple-zone production in the same wells from overlying sands and conglomerates, or adjacent beds. The same is true of chert production, but to a less extent.

Practically all of the daily production of 15,000 barrels from fractured "basement rocks" comes from three fields: Edison, Santa Maria Valley, and Wilmington. El Segundo and Playa del Rey add a relatively small amount, probably not more than 400–500 barrels.

The fact that three or possibly four oil fields produce commercially from "basement rocks" has had some rather far-reaching effects. In many fields exploratory wells are not only drilled through the sedimentary beds but into the underlying basement series. Many thousand dollars have been spent and will be spent in drilling to great depths and into "basement rocks" in an attempt to find conditions similar to Edison, Santa Maria Valley, and Wilmington. The geologist so unfortunate as to be drilling an exploratory well can no longer stop the well at any point short of actual penetration of the basement series, that is, without a lot of debate.

Certainly the most important commercial production in fractured rocks in this state is from the fractured Miocene cherts in northern Santa Barbara County. Here there are whole oil fields, or the major part of single fields, producing from fractured cherts. Santa Maria Valley, West Cat Canyon, Gato Ridge, Orcutt, and Lompoc are typical. Not all of the oil production from these fields comes from fractured cherts, but a goodly part does. At the present time, it is estimated that approximately 40,000 barrels of oil per day is being produced from this source.

These chert beds are definite lithologic units and can be recognized and correlated by means of electric logs. Wells can be completed in much the same manner as wells in sand-zone fields. Definite intervals of penetration can be taken and it can be determined when the producing zone has been penetrated, and in many other respects fractured chert reservoirs are similar to sand reservoirs. These conditions do not all prevail in the fractured "basement rocks." Oil production can be by edge-water drive or by gas expansion. There is a definite decline in production; there is well interference; wells may flow or have to be pumped upon completion; *et cetera*.

However, there is one factor in the study of fractured rock reservoirs which, so far as the writer knows, has defied analysis by petroleum and production engineers, and that is the measurement of the oil-volume content of the reservoir. A sand count of a sand reservoir can be made, and from a sand analysis the porosity, connate water, and the other factors necessary in order to calculate the tank oil in place can be determined, in terms of recovery per acre-foot of sand. This can not be done in a fractured rock reservoir and therefore any estimate of re-

serves is nothing more than a guess until a great deal of well and field history has been developed. Rates of decline can be observed which do not differ in kind from sand reservoirs, and an estimate can be made of the future production from individual wells. However, until a field is in a very advanced stage of development, no really good prediction can be made about the production that can reasonably be expected from an undrilled location.

Of course, as a field is developed, it can be observed that the wells begin to follow a general pattern, but due to the unpredictable fracturing which may be encountered at a chosen location, no assurance can be given that any individual well will follow that pattern. It is true that at some stage in the development of a pool, calculations can be made, based on a materials balance which will indicate the amount of tank oil active in the reservoir.

Another difference between the more familiar sand-reservoir oil fields and the fractured rock types is faulting, or intense deformation. Sand reservoirs can occur in areas of gentle folding; this is not so in the case of the fractured rock reservoir. The best wells in a fractured rock reservoir are in areas of known or suspected faulting, or intense folding. The rocks must be brittle and they must be broken. It is believed that some poor wells are the result of secondary deposition of calcite in the fractures.

A clue as to the economic importance of oil production from fractured chert reservoirs may be gained by summarizing the performance of some typical fields. The fields best suited for such an analysis are Casmalia, West Cat Canyon, Gato Ridge, Lompoc, Orcutt, and Santa Maria Valley.

In this group of fields, approximately 712 wells have produced 185,000,000 barrels of oil from fractured chert reservoirs, or an average of 260,000 barrels per well. Approximately 660 wells are now producing 39,000 barrels per day from these fields. It is estimated that there are 12,000 productive acres involved, which indicates a past recovery of 15,400 barrels per acre.

In view of the fact that some of these fields are in advanced stages of depletion while others are relatively flush, it would be difficult to make a reasonable estimate of expected future recovery.

There are two fields that produce from "basement rocks" under conditions believed favorable for making an analysis. These fields are the Knoxville pool in Santa Maria Valley and the Schist pool in the Edison field. El Segundo, Playa del Rey, and Wilmington are excluded from this analysis because so much of the oil is produced from sands and conglomerates close to or adajcent to the basement that it is impossible to differentiate between basement oil production and production from overlying beds. This is in some measure also true of the Knoxville pool.

In the Knoxville pool of the Santa Maria Valley, which was discovered in 1942, although extensive development did not take place until about 1944, 76 wells have produced approximately 6,600,000 barrels of oil, or an average of 86,000 barrels per well, and these wells are now producing 4,300 barrels per day. It

is estimated that approximately 1,170 acres are productive, which indicates a past recovery of 5,640 barrels per acre.

In the Schist pool at Edison, discovered in 1945, 116 wells have produced 6,100,000 barrels of oil, or an average of 52,500 barrels per well, and these wells are now producing 7,250 barrels per day. It is estimated that approximately 1,300 acres are productive, which indicates a past recovery of 4,700 barrels per acre.

It appears that these pools will produce ultimately between 12,000 and 18,000 barrels per acre from fractured "basement rocks." These are not impressive figures, and should be of concern to any geologist who recommends a 10,000- or 12,000-foot well to test "basement rocks."

El Segundo has frequently been cited as an example of production from "basement rocks." This field has had a total production of 11,800,000 barrels from 900 productive acres. The recovery of 13,000 barrels per acre, which includes production from the overlying sands and conglomerates, does not indicate the "basement rocks" to be very productive in terms of per-acre yield.

Playa del Rey will always remain an enigma as to the actual amount of oil production that can be attributed to the "basement rocks," for the reason that many wells, which are thought to have penetrated the actual schist basement probably drilled only into a schist boulder in a detrital agglomerate.

Wilmington, the one remaining field of any importance that produces from "basement rocks," lacks sufficient history to give much in the way of analytical data. It would be of interest if at some future date oil production and recovery figures could be analyzed with the object of determining actual recovery per well and per acre.

In conclusion, it has been observed that a great many wells, producing from fractured rock reservoirs, have open to production, intervals ranging in thickness from 500 to 1,000 feet, and there are wells in which more than 2,000 feet of penetration has been made. In general, it can be stated, that fractured rock reservoirs are not as productive as sand reservoirs per foot of penetration.

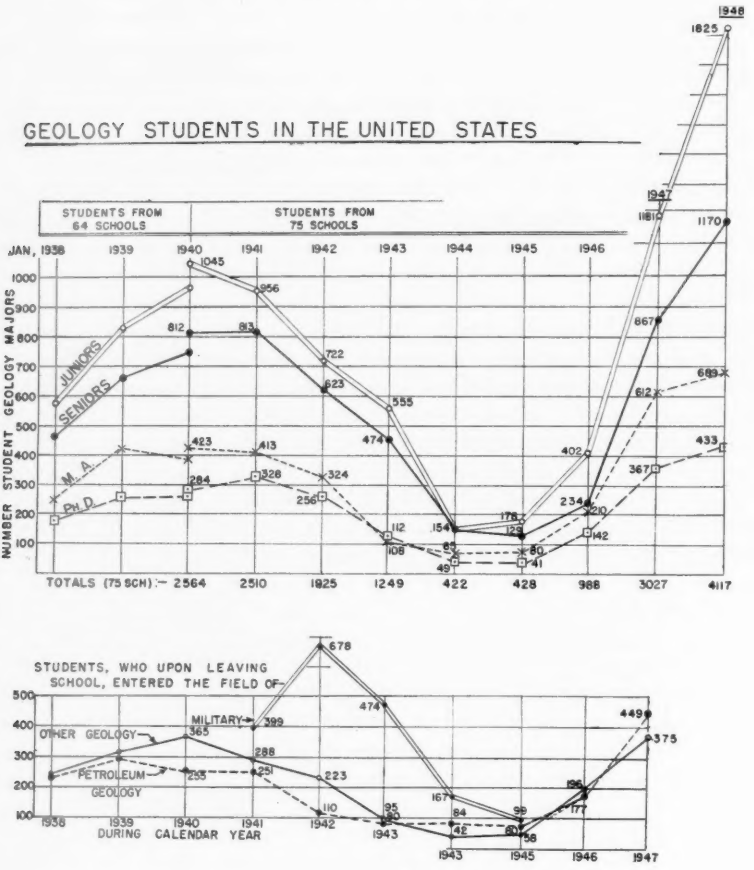
BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1356-1357, 1 CHART

# RESEARCH NOTES

## SURVEY OF COLLEGE STUDENTS MAJORING IN GEOLOGY

A. I. LEVORSEN[1]
Stanford University, California

The chart is a continuation of the surveys of recent years. It shows the trend in the number of college students majoring in geology in the United States, and the placement of




[1] Dean of the School of Mineral Sciences.

those leaving school during the calendar year, 1947. The latest figures are for January, 1948. In considering the chart, it should be remembered that the figures as of January, 1948, include only the enrollment in the first semester of those colleges using the two-semester systems, and the enrollment for the second quarter of those colleges using the quarter system.

---

## MISSISSIPPI GEOLOGICAL SOCIETY FIELD TRIP, JUNE 18–20

The 6th Field Trip of the Mississippi Geological Society was conducted through the post-Claiborne sediments of Mississippi from June 18–20. Secretary-treasurer E. T. MONSOUR reports that the attendance was 150. Twenty exemplary outcrops were visited, discussed, and collected. JAMES A. WATERS, presented an oral paper on "Stratigraphy and Paleogeography of the Catahoula-Frio Formation." The guidebook, entitled "Upper Eocene, Oligocene, and Lower Miocene of Central Mississippi," contains an introductory paper by GROVER E. MURRAY; a geologic map of central Mississippi; one strike and three dip electrical-log sections; a correlation chart and "Generalized Stratigraphic Discussion of Post-Claiborne Sediments in Mississippi and Correlation with Equivalent Age Sediments in the Gulf Coast Province," by E. T. MONSOUR; a paper on "The Jackson (Eocene) and Younger Beds of West-Central Mississippi," by E. P. THOMAS; and one entitled "Notes on the Stratigraphy of Northeastern Wayne County, Mississippi," by W. J. HENDY. The road log describes all stops made on the trip and includes cross-sectional profiles of stops 8–19. There are reprinted, for accessibility, excerpts from the Shreveport Geological Society 11th Annual Field Trip Guidebook entitled "Stratigraphy and Paleontological Notes on the Eocene (Jackson Group), Oligocene, and Lower Miocene of Clarke and Wayne Counties, Mississippi." Copies of the guidebook may be obtained, at $5.15 per copy prepaid, by writing E. T. MONSOUR, Secretary-Treasurer, Box 2571, West Jackson, Mississippi. Students may obtain copies for $3.15 prepaid, through their professors.

---

The annual fall meeting of the Pacific Section of the Association is scheduled to be held on October 28–29 at the Huntington Hotel, Pasadena, California.

E. FLOYD MILLER, who has been with A. G. OLIPHANT for several years, is now special representative for the Phillips Petroleum Company. His office is 1507 Philtower Building, Tulsa, Oklahoma.

H. M. KIRK has been appointed manager of Compania Petrolera de Peten S. A., 5a Avenida Sur 21, Guatemala, C. A., a newly organized company which will commence an exploration program in northern Guatemala. He was formerly with the Atlantic Refining Company of Cuba in Havana, Cuba.

KENNETH H. CRANDALL, vice-chairman of the board of The California Company, has been elected a director of the Standard Oil Company of Texas. Both companies are subsidiaries of Standard Oil Company of California.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1358-1365

# REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

---

## STRUCTURAL GEOLOGY OF REGION BETWEEN MIZIL AND TARGOVISTI [ROUMANIA], WITH SPECIAL REFERENCE TO COAL IN DACIAN, BY N. ONCESCU

REVIEW BY WALTER M. SMALL[1]
Cooperstown, Pennsylvania

*"Structura geologica a regiunii dintre Mizil si Targoviste, cu privire speciala asupra carbunilor din Dacian" (Structural Geology of Region between Mizil and Targovisti [Roumania], with Special Reference to Coal in Dacian), by N. Oncescu. *Geol. Inst. Roumania Tech. and Econ. Studies*, Ser. A, Econ. Geol., No. 3 (Bucharest, 1947). 62 pp., 7 figs., 1 geol. map in colors.

ABSTRACT

Dacic lignite beds, with a thickness of 1–3 meters, have been exploited locally. Attention should be given these coals because the nation's forests are being reduced rapidly and oil as a fuel has been since 1939 almost unobtainable for household uses. The crisis will bring about an increased search for coal. Some local exploitation of the Dacic coals of the Subcarpathians has occurred, in a rudimentary way at Golesti, Doicesti, Sotanga, Filipesti de Padure, Ojasca, and other places.

The low heating value of the Dacic coal should not prevent its use, particularly for electric-power plants. The purpose of the report is to point out areas which might be proved favorable for such exploitation.

Well records of the Dumbovita and Prahova districts have been used in the study to ascertain the thickness, number, and depth of the coal beds. While the well logs have not been entirely satisfactory for this, map No. 1 has been prepared by using them to determine isobaths.

In the areas of Dacic oil or gas production, coal mining in the Dacic would be very hazardous; a map (No. 2) has been prepared showing the situation. Even where the Dacian does not contain oil or gas, there is the grave danger of leakage on structures with Meotic production, through old or defective casing or bad cementing jobs in the wells. It so happens that many of the structures which bring the Dacic coals within reach of shafts and tunnels are oil- or gas-producing, thus limiting the exploitation of possibilities of the coal beds.

Three categories of anticlines are discussed. The first are those with the Levantine or Recent deposits over the crest. Formation contacts from well logs are given for Brazi, Manesti-Vladeni, Capsuna-Suta Seaca, Bucov-Buda, Aricesti, and Podenii Vechi, all rather deep for exploitation of lignites, and several with gas in the Dacic sands. Those with the Levantine beds in the crest are Margineni, Boldesti, and Bucsani, all with the coal beds deep and with Dacic gas. The second category, or those with salt diapirs, include Baicoi-Tintea, Floresti, Moreini-Gura Ocnitei, and Ochiuri, and, although the coals are shallow in places, none may be recommended for mining because of the pressure of oil and gas. The third category, anticlines with the axes eroded into the upper Pliocene, are the

[1] Consulting geologist. Review received, April 21, 1948.

Ceptura-Urlati, Silistea-Dealului-Filipesti-Calinesti-Edera-Cervenia, Chiru-Dealul Batran-Viforata-Teis, Doicesti-Sotanga, Sateni, and Margineanca. A possible reserve of 40 million tons is given the first; Silistea should have a reserve of about 60 million tons and is strongly recommended for exploitation; a small area near Teis may be of interest; and the last three mentioned already have a few mines in operation.

The fact is pointed out that in a region of such complicated structure, borings or shafts should be made in advance to determine the thickness and extent of the coal beds. The data obtained from oil-well logs are not sufficiently detailed and the sample records are not a basis for positive estimates. Holes of 600–700 meters depth with the beds sampled carefully will be needed to prove adequate reserves before opening mines and building a power plant.

COMMENTS BY TRANSLATOR

The author has made good use of a great number of well logs from the oil fields of the region. His structure-contour map on the top of the Dacian is very interesting both for this report and for those who wish to have a general idea of the structure of the upper Pliocene. The reviewer would point out that there may be errors in recognizing the top of the formation in several localities due to a lack of definite break or change in sedimentation. Farther west, there are lignite beds in the basal Levantine, as well as in the Dacian.

The petroleum gologist will find the structure sections through the various oil pools interesting and instructive. They are clearly shown on the map which is too small to show all well locations. Many well elevations and formation contacts down to the top of the Miocene are given.

From a practical standpoint, mention should be made of the difficulty of mining in unconsolidated formations, the steep dips found in most structures, and the lenticularity of the lignites. The author is entirely correct in stressing the necessity of proving the structure and extent of a reserve before starting operations.

The report was signed, July 24, 1943, and published in 1947. The fuel shortage which prompted the investigation then has not been relieved. One would surmise that it is more acute, with little prospect for betterment in the near future. The cities and industries supplied with natural gas from Transylvania are fortunate as long as these reserves last; the greater part of the country remains as before, with precarious fuel supply. For a long time it has been recognized that the deforestation of the Carpathians and the Subcarpathian region was a menace. Legislation to require replanting after cutting the timber was ineffectual. The Subcarpathian hills present difficult and unique soil-erosion problems, the character of the young Tertiaries and their structure conspiring to complicate matters. The Roumanian expression, "Pamant fugitive," meaning "fleeing ground or soil," is very appropriate. This is particularly bad in the Levantine and Dacian, whole orchards or farmsteads simply sliding toward the valleys. The flow is ordinarily about root depth of the vegetation and its surface commonly developes a miniature glacier-like topography with cracks and shearing action.

The fuel shortage mentioned in this report will continue to produce injudicious cutting of forests and young growth, which in turn will increase soil erosion and displacement of population.

## GUIDE TO THE GEOLOGY OF CENTRAL COLORADO, QUARTERLY OF COLORADO SCHOOL OF MINES

*"Guide to the Geology of Central Colorado," *Quar. Colorado School Mines*, Vol. 43, No. 2 (Golden, April, 1948). 176 pp., 38 figs., 14 pls. Price, $3.00.

Publication of the "Guide to the Geology of Central Colorado," Volume 43, Number 2 of the *Quarterly* of the Colorado School of Mines has been announced by H. M. Crain, director of publications at the school. This issue of the *Quarterly* was published as the guidebook for the three field trips of the thirty-third annual meeting of the American Association of Petroleum Geologists in Denver, April 26–29.

The publication comprises 176 pages including 38 figures. In addition, there are 14 plates, including one 24-by-28-inch index map of Colorado, showing major geologic structure and significant oil and gas information.

In addition to discussions of principal features of the areas in which the field trips are made, and road logs for the trips, there are authoritative articles on the geology of the eastern flank of the Front Range of Colorado; the Kokomo, Gilman, and Leadville mining districts; the Climax molybdenite deposit; the oil-shale deposits in the vicinity of the naval oil-shale reserve, Garfield County; the oil-shale demonstration plant at Rifle; and the geology of South Park.

Contributors include the following well known geologists from the consulting and educational fields and from the United States Geological Survey: John W. Vanderwilt, Francis M. Van Tuyl, Warren O. Thompson, Carroll E. Dobbin, Charles S. Lavington, Thomas S. Harrison, Arthur E. Brainerd, Harry W. Oborne, Don B. Gould, Gordon Hurd, B. Warren Beebe, Everett S. Shaw, A. Herbert Koschmann, Ogden L. Tweto, Donald C. Duncan, and Norman M. Denson.

The guidebook may be obtained from the department of publications, Colorado School of Mines, Golden, at $3.00 a copy, postpaid.

---

## RECENT PUBLICATIONS

### ARIZONA

*"Geomorphology of the Valley of the Little Colorado River, Arizona," by Orlo E. Childs. *Bull. Geol. Soc. America*, Vol. 59, No. 4 (New York, April, 1948), pp. 353–88; 4 pls., 7 figs.

### AUSTRALIA

*"A Study of Australian Diatomites with Special Reference to Their Possible Value as Filter Media," by Irene Crespin. *Australia Bur. Min. Resources Bull. 7*, Misc. Ser. 3 (Canberra, 1947). 40 pp., 6 pls., distribution chart.

### BELGIAN CONGO

*"Note préliminaire sur les algues des séries calcaires anciennes du Congo Belge" (Preliminary Note on Algae in the Old Calcareous Rocks of the Belgian Congo), by L. Cahen, A. Jamotte, J. Lepersonne, and G. Mortelmans. *Congo Belge et Ruanda-Urundi Service Géologique Bull. 2* (1946), Fasc. II (Léopoldville, Congo Belge), pp. 172–236; 23 figs. French.

*"Etat actuel des reconnaissances relatives à la stratigraphie des systèmes du Kalahari et du Karroo au Congo Belge" (Status of Stratigraphic Reconnaissance of the Kalahari and Karro Systems in Belgian Congo), *ibid.*, pp. 237–89; 2 figs.

CALIFORNIA

*"Geology of the Tecopa Area, Southeastern California," by John R. Mason. *Bull. Geol. Soc. America*, Vol. 59, No. 4 (New York, April, 1948), pp. 333–53; 2 pls.

*"The Basement Complex in Well Samples from the Sacramento and San Joaquin Valleys, California," by J. C. May and R. L. Hewitt. *California Jour. Mines and Geology*, Vol. 44, No. 2 (San Francisco, April, 1948), pp. 129–58; 8 pls., 4 charts.

CANADA

"Trilobita of the Ottawa Formation of the Ottawa-St. Lawrence Lowland," by Alice E. Wilson. *Geol. Survey Canada Bull. 9* (Ottawa, April, 1948).

"Geology and Economic Minerals of Canada" (3d ed.), by officers of the Geological Survey. *Geol. Survey Canada*, Econ. Geol. Ser. 1 (Ottawa, April, 1948). "This report, which should be read in conjunction with the recently issued Geological Map of Canada (820A-50 cents), summarizes the geological investigations and mineral developments that have taken place during the century or more since the founding of the Geological Survey of Canada in 1842. The data given have been collected mainly from the more detailed descriptions in the separate publications of the Geological Survey." Price, $0.75.

"Early Carboniferous Strata of St. Georges Bay Area, Newfoundland," by W. A. Bell. *Geol. Survey Canada Bull. 10* (Ottawa, May, 1948).

"Brule and Entrance Map Areas, Alberta," by A. H. Lang. *Geol. Survey Canada Mem. 244* (Ottawa, May, 1948).

COLORADO

"Geologic Map Index of Colorado" (May, 1948), compiled by Leona Boardman and Annabel Brown. One of a series titled "Index to Geologic Mapping in the United States." Sheet, 29×44 inches. Scale, 1 inch equals 12 miles. Available from Director, Geological Survey, Washington, D. C. Price, $0.70.

*"Guide to the Geology of Central Colorado," by many contributors. *Colorado School of Mines Quar.*, Vol. 43, No. 2 (Golden, April, 1948). 176 pp., 38 figs., 14 pls., including a 24×28-inch index map of Colorado, showing major geologic structure and significant oil and gas information. Published as the guidebook for the three field trips of the 33d annual meeting of the A.A.P.G., Denver, April 26–29, 1948. Department of Publications, Colorado School of Mines, Golden. Price, $3.00.

*"Subsurface Geologic Cross Section from Baca County to Yuma County, Colorado," by John C. Maher. *Kansas Geol. Survey Prelim. Cross Sec. 6* (Lawrence, Kansas, 1948). 11 pp.; folded sheet, 43×35 inches. Price, $0.25.

*"Oil-Shale Resources of Colorado, Utah, and Wyoming," by Carl Belser. *Petrol. Tech.*, Vol. 11, No. 3 (New York, May, 1948). 11 pp., 6 figs. *A.I.M.E. Tech. Pub. 2358.*

CUBA

*"List of Palmer Cuban Fossil Localities," by Robert H. Palmer. *Bulletins of American Paleontology*, Vol. 31, No. 128 (Paleontological Research Institution, Ithaca, New York, May 1, 1948). 178 pp., 2 maps.

EUROPE

*"Oil Mining in Europe," by A. E. Gunther. *Petrol. Engineer*, Vol. 19, No. 8 (Dallas, Texas, May, 1948), pp. 74, 79–80, 82, 84, illus.

GENERAL

*"Some Practical Problems for Secondary Recovery Research," by Richard V. Hughes. *Producers Monthly*, Vol. 12, No. 7 (Bradford, Pennsylvania, May, 1948), pp. 21–27.

*"New Evidence of the Origin of Pre-Cambrian Carbon," by Kalervo Rankama. *Bull. Geol. Soc. America*, Vol. 59, No. 5 (New York, May, 1948), pp. 389–416; 6 pls., 4 figs.

*"Time-Stratigraphic Classification of Sedimentary Rocks," by Hollis D. Hedberg. *Ibid.*, pp. 447–62.

**Eruptive Rocks*, by S. James Shand. Their genesis, composition, classification, and their relation to ore deposits, with a chapter on meteorites. 3d ed. (1947). 488 pp., 4 pls., 51 figs. 5.5×8.25 inches. Cloth. John Wiley and Sons, Inc., 440 Fourth Avenue, New York 16, N. Y. Price, $7.50.

*"Coral Reefs—A Review," by Reginald A. Daly. *Amer. Jour. Sci.*, Vol. 246, No. 4 (New Haven, Connecticut, April, 1948), pp. 193–207.

*"Our Petroleum Resources," by A. I. Levorsen. *Bull. Geol. Soc. American*, Vol. 59, No. 4 (New York, April, 1948), pp. 283–300; 12 figs.

*"Stratigraphical Paleontology," by Raymond C. Moore. *Ibid.*, pp. 301–26; 9 figs.

*The Petrography and Petrology of South African Clays*, by V. L. Bosazza. 313 pp. Frontispiece and 17 pls., 15 figs. 7.25×9.75 inches. Printed by Percy Lund, Humphries and Company, Ltd., 12 Bedford Square, London, W. C. 1. Price, Clothbound, L 2-2-0.

*Mineral Resources of the United States*, prepared by the U. S. Bureau of Mines and the U. S. Geological Survey. Includes chapters on 39 minerals and commodities. Many tables, charts, maps. Public Affairs Press, 2153 Florida Avenue, N. W., Washington, D. C. Price, $5.00.

*"Natural Gas, Coal, Oil Shale as Sources of Liquid Fuels," by E. V. Murphee. *Oil and Gas Jour.*, Vol. 46, No. 49 (Tulsa, April 8, 1948), pp. 66–70, 95–96; 2 figs., 5 tables.

*"Wildcat Drilling in 1947," by Frederic H. Lahee. *Ibid.*, pp. 79–85; 2 figs., 4 tables. Digest of complete article, which was published in A.A.P.G. June *Bulletin*.

*"Report of the Committee on a Treatise on Marine Ecology and Paleoecology, 1946–1947, No. 7," by Harry S. Ladd, chairman, *et al. Division of Geology and Geography, National Research Council* (Washington, D. C., March, 1948). 93 multigraphed pp. 8.5×11 inches. Paper cover. Price, $1.00.

*Rotary Drilling Handbook* (4th ed., 1948), by J. E. Brantly. 560 pp., 200 pp. of tables and formulas. Petroleum World, 412 West 6th Street, Los Angeles, California. Price, $7.50.

*"Oil-Shale Mining," by Tell Ertl. *Petrol. Tech.*, Vol. 11, No. 3 (New York, May, 1948). 8 pp., 6 figs. *A.I.M.E. Tech. Pub. 2359*.

*"Oil-Shale Processing," by J. D. Lankford and Boyd Guthrie. *Ibid.* 12 pp., 8 figs. *A.I.M.E. Tech. Pub. 2360*.

*"La notion du bassin sédimentaire donnée essentielle pour guider les recherches de pétrole" (The Sedimentary Basin as a Guide in Exploration for Petroleum), by M. Bruderer. *Bull. Assoc. Francaise Tech. Pétrole*, No. 68 (Paris, April 1, 1948), pp. 1–18; 13 figs. French. A.F.T.P., 44, Rue de Rennes, Paris 6.

GERMANY

*"Secondary Recovery of Crude Oil in Germany," by Walter Ruhl. *Producers Monthly*, Vol. 12, No. 7 (Bradford, Pennsylvania, May, 1948), pp. 16–20.

ILLINOIS

*"Biostratigraphic Studies of the Niagaran Inter-Reef Formations in Northeastern Illinois," by Heinz A. Lowenstam. *Illinois State Museum Sci. Papers*, Vol. 4 (Springfield, 1948). 146 pp., 8 pls., 1 fig.

IRAN

*"Oil Production from Fields of Southwestern Iran," by H. S. Gibson. *World Petroleum*, Vol. 19. No. 5 (New York, May, 1948), pp. 62–66, and 128; 8 figs.

KANSAS

"Kansas Clay, Dakota Formation," by Norman Plummer and John F. Romary. *Kansas Geol. Survey Bull. 67* (Lawrence, December, 1947). 241 pp., 7 pls., 17 figs., 27 tables.

*"Ground-Water Resources of the Kansas City, Kansas, Area," by V. C. Vishel. *Ibid., Bull. 71* (February, 1948). 109 pp., 3 pls., 12 figs., 9 tables.

*"Graphic Representation of Oil-Field Brines in Kansas," by Russell M. Jeffords. *Kansas Geol. Survey Bull. 76*, Pt. 1 (Lawrence, 1948). 12 pp., 6 figs.

*"Contamination of Deep Water Wells in Southeastern Kansas," by Charles C. Williams. *Ibid.*, Pt. 2. 28 pp., 3 figs.

*"The Occurrence of Corals in Late Paleozoic Rocks of Kansas," by Russell M. Jeffords. *Ibid.*, Pt. 3. 53 pp., 3 pls; 3 figs., 2 tables.

MISSISSIPPI

*"Geology and Artesian Water of the Alluvial Plain in Mississippi," by Glen Francis Brown. *Mississippi Geol. Survey Bull. 65* (University, 1947). 424 pp., 38 figs., 13 pls., 30 tables.

"Correlation of Pre-Selma Upper Cretaceous Rocks in Northeastern Mississippi and Northwestern Alabama," by D. Hoye Eargle. *U. S. Geol. Survey Prelim. Chart 35*, Oil and Gas Inves. Ser. (April, 1948). Sheet, 41×41 inches. Available from Director, Geological Survey, Washington 25, D. C. Price, $0.50.

NETHERLANDS

*"Bijdrage tot de Kennis van het Boven-Senoon in Zuid-Limburg" (Upper Senonian [Cretaceous] in South Limburg), by C. Francken. *Mededeel. Geol. Stichtung*, Ser. C-VI-No. 5 (1948). 148 pp., 9 figs., 3 pls. Dutch with English summary. Published by Ernest van Aelst, Witmakerstraat 25, Maastricht. Price, f. 7.50.

*"Het Kwartair van het Peel-Gebied en de Naaste Omgeving" (Quaternary in the Region of Peel), by J. I. S. Zonneveld. *Ibid.*, Ser. C-VI-No. 3 (1947). 223 pp., 17 figs., 6 pls., 5 tables. Dutch, with French résumé. A petrographic study. Price, f. 11.80.

*"De stratigrapfische Grens tussen het Plistoceen en het Holoceen in Nederland" (Stratigraphic Boundary between Pleistocene and Holocene in Netherlands), by H. D. M. Burch, F. Florschutz, and P. Tesch. *Geologie en Mijnbouw*, Vol. 10, New Ser., No. 5 (Spaarne 17, Haarlem, May, 1948), pp. 109–15. Dutch, with English abstract.

NEW MEXICO

*"The Eocene of the San Juan Basin, New Mexico, Part I," by George Gaylord Simpson. *Amer. Jour. Sci.*, Vol. 246, No. 5 (New Haven, Connecticut, May, 1948), pp. 257–82; 2 figs.

NORTH DAKOTA

"Geologic Index Map of North Dakota" (May, 1948), compiled by Leona Boardman and Annabel Brown. Scale, 1 inch equals 12 miles. Available from Director, Geological Survey, Washington 25, D. C. Price, $0.40.

OKLAHOMA

*"Secondary-Recovery Possibilities of the Western Part of the Delaware-Childers Field, Nowata County, Oklahoma," by I. W. Fox, R. L. Ginter, and G. P. Alden. *U. S. Geol. Survey* (Tulsa, Oklahoma, 1948). 113 pp., 20 tables, 33 pls. Paper cover, 8.5×11 inches. Multigraphed. Copies may be had by interested lessees and operators upon request to the Oil and Gas Supervisor, U. S. Geological Survey, Federal Building, Tulsa.

"The Morrow Series of Northeastern Oklahoma," by Carl A. Moore. *Oklahoma Geol. Survey Bull. 66* (Norman, 1948). Includes 96 measured outcrop sections, many shown graphically. Price, $0.80, postpaid.

PACIFIC REGION

*"Major Structural Features of the Western North Pacific, an Interpretation of H. O. 5485, Bathymetric Chart, Korea to New Guinea," by H. H. Hess. *Bull. Geol. Soc. America*, Vol. 59. No. 5 (New York, May, 1948), pp. 417–46; 2 pls., 9 figs.

*Geotektonische Forschungen*, edited by H. Stille and Fr. Lotze. Heft 7–8. "Die tektonische Entwicklung der pazifischen Randgebiete II" (Tectonic Development of the Region Surrounding the Pacific II). Articles by H. Stille, G. Y. Lee and H. Köbel. 323 pp., illus. Published by Gebrüder Borntraeger, Berlin-Zehlendorf (1945). In German.

ROCKY MOUNTAINS

*"Waters of Producing Fields in the Rocky Mountain Region," by James G. Crawford. *Petrol. Tech.*, Vol. 11, No. 3 (New York, May, 1948). 23 pp., 35 tables. *A.I.M.E. Tech. Pub. 2383.*

SPAIN

*Geotektonische Forschungen*, edited by H. Stille and Fr. Lotze. Heft 6. "Zur Geologie der Iberischen Meseta I" (Geology of the Iberian Meseta I). Articles by Fr. Lotze, W. Clark, and P. Schmidt-Thomè. 92 pp., illus. Published by Gebrüder Borntraeger, Berlin-Zehlendorf (1945). In German.

TENNESSEE

*"Oil and Gas Possibilities of Southwestern Tennessee; by Carl A. Mortiz. *World Oil*, Vol. 128, No. 1 (Houston, Texas, May, 1948), pp. 160–70; 5 figs., 2 tables.

UTAH

*"Geology and Geography of Central Kane County, Utah," by Herbert E. Gregory *Bull. Geol. Soc. America*, Vol. 59, No. 3 (New York, March, 1948), pp. 211–48; 9 pls., 2 figs.

"List of wells drilled for oil and gas in Utah" (May, 1948). Shows locations, counties, fields, well numbers, operators, elevations, surface and bottom-hole geologic formations, producing formations with depths, total depths, and status of 550 wells. Limited number of copies available to qualified applicants aiding exploration in Utah. U. S. Geological Survey Oil and Gas Supervisor, Box 400, Casper, Wyoming.

"Geology of the Bituminous Sandstone Deposits near Sunnyside, Carbon County, Utah," by Clifford N. Holmes, Ben M. Page, and Paul Averitt. *U. S. Geol. Survey Prelim. Map 86*, Oil and Gas Inves. Ser. (May, 1948). Sheet, 32×52 inches. Maps, sections, text. Available from Director, Geological Survey, Washington 25, D. C. Price, $0.50.

*"Some Features of the Navajo Formation in Zion National Park, Utah," by Russell K. Grater. *Amer. Jour. Sci.*, Vol. 246, No. 5 (New Haven, Connecticut, May, 1948), pp. 311–18; 2 pls., 1 fig.

WYOMING

"Geology of the Worland-Hyattsville Area, Big Horn and Washakie Counties, Wyoming," by C. P. Rogers, Jr., *et al. U. S. Geol. Survey Prelim. Map 84*, Oil and Gas Inves. Ser. (May, 1948). Sheet, 44×58 inches. Scale, 1 inch equals 4000 feet. Available from Director, Geological Survey, Washington 25, D. C. Price, $0.90.

---

ASSOCIATION DIVISION OF PALEONTOLOGY AND MINERALOGY

**Journal of Sedimentary Petrology* (Tulsa, Oklahoma), Vol. 18, No. 1 (April, 1948).

"Microstylolites in Sandstone," by Laurence L. Sloss and Dan E. Feray.

"A Code for Expressing Grain Size Distribution," by K. O. Emery and Howard Gould.

"Volcanic Glass, Allanite and Zircon as Characteristic Minerals of the Toba Rhyolite at Sumatra's East Coast," by H. W. van der Marel.

"Underway Bottom Sampler," by K. O. Emery and A. R. Champion.

"New Snapper-type Sea Floor Sediment Sampler," by E. C. LaFond and R. S. Dietz.

"Weathering and Heavy Minerals," by Victor T. Allen.

"A Simple Volumeter," by Robert L. Miller.

**Journal of Paleontology* (Tulsa, Oklahoma) Vol. 22, No. 3 (May, 1948).

"A Foraminiferal Fauna from the Kaiatan State (Upper Eocene) of New Zealand," by J. M. Dorreen.

"Three Notes on Ordovician Cystids," by G. Winston Sinclair.

"Middle Cambrian Trilobites from the Conglomerates of Quebec," by Franco Rasetti.

"Lower Cambrian Pleospongia from the Purcell Range of British Columbia, Canada," by Vladimir J. Okulitch.

"A Lower Permian Ammonoid Fauna from New Mexico," by A. K. Miller and Eldon J. Parizek.

"A Small Amphibian from the Triassic of Howard County, Texas," by John Andrew Wilson.

"Fossil Helioporidae from Japan and the South Sea Islands," by Motoki Eguchi.

"A New *Spongiomorpha* from the *Orbitolina* Sandstone of Iwate Prefecture, and Its Significance in Japan," by Motoki Eguchi.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1366-1381

# ASSOCIATION ROUND TABLE

## NOMINATING COMMITTEE

The executive committee has appointed the following members of the nominating committee.

EDGAR W. OWEN, San Antonio, Texas
JOHN L. FERGUSON, Tulsa, Oklahoma
FRANK A. MORGAN, Los Angeles, California
BEN H. PARKER, Golden, Colorado
JOHN P. SMOOTS, Cleveland, Ohio

Pertinent excerpts from the by-laws and the constitution are here quoted.

By-Laws. *Committees, Article VI. Nominating committee, Section 14.*—

The purpose of the nominating committee is to nominate candidates for the Association offices as provided in the constitution. The committee shall consist of a chairman and four other members appointed by the executive committee to serve one year. At least two members of the nominating committees shall be past officers of the Association.

Constitution. *Officers and their duties, Article IV. Officers, Section 1.*—

The officers of the Association shall be a president, a vice-president, a secretary-treasurer, and an editor. These, together with the past-president, shall constitute the executive committee and managers of the Association.

*Section 2.*—The officers shall be elected annually from the Association at large by secret mailed ballot in the following manner. The nominating committee shall nominate one or more candidates for each office, and its nominations shall be published in the September *Bulletin*. Additional nominations may be made by written petition of fifty, or more, members in good standing received at Association headquarters not later than November 15. The executive committee shall then prepare a printed ballot, listing the candidates for each office, and one ballot shall be mailed to each member as soon after November 15 as possible. Ballots returned to Association headquarters on or before January 31 shall be placed as received in a locked ballot box and promptly after January 31 the ballot committee shall open the ballot box and count the ballots. Ballots of delinquent members shall not be counted. A majority of all votes cast for an office is necessary for election. If there are three or more nominees for any office, a preferential form of ballot shall be used. In case of a tie vote, the executive committee shall cast one additional deciding vote. Each candidate, when voted for as a candidate for the particular office for which he is nominated, shall be thereby automatically voted for as a candidate for the executive committee for one year, except that candidates for the presidency shall be automatically voted for as candidates for the executive committee for two years.

*Section 3.*—No one shall hold the office of president for two consecutive years and no one shall hold any other office for more than two consecutive years except the editor who shall not hold office for more than six consecutive years.

## MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Com-

mittee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Thomas William Amsden, Baltimore, Md.
H. E. Vokes, W. A. Cobban, Joseph T. Singewald, Jr.
Mary Elizabeth Barnes, Champaign, Ill.
L. E. Workman, Alfred H. Bell, David H. Swann
Maurice Lyman Brashears, Jr., Jamaica, N. Y.
Nicholas A. Rose, V. T. Stringfield, A. N. Sayre
Nathaniel Paige Brown, Oklahoma City, Okla.
Richard B. Rutledge, E. A. Markley, Glen S. Norville
Harold Leslie Copeland, Caracas, Venezuela, S. A.
Guillermo Zuloaga, James S. Cullison, K. F. Dallmus
Bernard Arthur Curvin, Oklahoma City, Okla.
Ben F. Baldwin, George H. Galloway, Erwin L. Selk
Norman Maclaren Denson, Denver, Colo.
N. W. Bass, J. D. Love, D. L. Blackstone, Jr.
Lloyd Robert Dreveskracht, Casper, Wyo.
George A. Thiel, Charles S. Agey, A. R. Denison
Cleon Boyd Forbes, Moore, Okla.
H. E. Itten, F. H. Schouten, W. C. Imbt
Pierre Freymond, Maracaibo, Venezuela, S. A.
H. P. Schaub, R. Martin, H. H. Renz
Donald C. Grange, Houston, Tex.
Hart Brown, Lewis H. Boyd, Willis H. Fenwick
William Randolph Green, Oildale, Calif.
Robert L. Rist, Stanley S. Siegfus, Charles W. Porter
William Herold Hager, Corpus Christi, Tex.
Charles W. Stuckey, Jr., J. M. Vetter, Gentry Kidd
Franz M. Hawpe, Tulsa, Okla.
G. D. Gibson, R. H. Tucker, Don Gilkison
Russell Edward Hayward, Bogota, Colombia, S. A.
A. D. Graves, Homer J. Smith, George H. Hazen
William Ross Sutherland Henderson, London, Ont., Canada
A. N. Mackenzie, G. W. Lepper, T. B. Williams
William Edwin Hendrix, San Gabriel, Calif.
W. H. Holman, Herschel L. Driver, Karl Arleth
Jack Roach Huffmyer, Dallas, Tex.
William N. Mosher, C. A. Mix, C. M. Linehan
Melvin L. Irwin, Houston, Tex.
George Dickinson, Sherwood Buckstaff, O. Wilhelm
David Keppel, Bogota, Colombia, S. A.
C. H. Dresbach, Hollis D. Hedberg, Augustin Pyre
John Hamilton Lapp, Tulsa, Okla.
Max Littlefield, Charles Ryniker, Robert F. Walters
Walton Sebastian Launey, Houston, Tex.
Edward D. Pressler, H. J. McLellan, Olin G. Bell
Raymond Georges Levy, Petitjean, French Morocco
H. de Cizancourt, L. Migaux, E. D. Lynton
Clyde Vernon Lisman, Jr.
W. M. Plaster, Joseph Purzer, W. C. Dennis

Wallace Eustace Lumb, Amarillo, Tex.
T. C. Craig, R. K. Lanyon, Walter G. Moxey
James Bernard Macelwane, St. Louis, Mo.
F. Goldstone, L. L. Nettleton, Paul Weaver
Emma Jean McBride, Fort Worth, Tex.
D. G. Stookey, Edwin M. Rowser, R. H. Schweers
Elbert Ferrell McMullin, Dallas, Tex.
Martin C. Kelsey, Barney Fisher, W. J. Hilseweck
Andrew Hamilton McNair, Hanover, N. H.
Edward J. Foley, Lewis B. Kellum, G. M. Ehlers
Frank Stutzman Millard, Ardmore, Okla.
Walter Neustadt, Jr., M. P. White, C. E. Hannum
Frederick Eugene Moran, Owensboro, Ky.
J. Albert Brown, Wallace Damron, Daniel J. Jones
Thomas Swint Napier, Dallas, Tex.
B. W. Walton, O. C. Clifford, Jr., A. E. McKay
John P. Paschall, Houston, Tex.
P. M. Konkel, T. O. Hall, W. A. Thomas
Kenneth Armstrong Payne, Houston, Tex.
Wayne V. Jones, F. E. Heath, A. P. Allison
J. Frank Rollins, Dallas, Tex.
M. C. Kelsey, W. J. Hilseweck, Barney Fisher
Rolf F. Rutsch, Berne, Switzerland
Max Bornhauser, Wolf Maync, Hans E. Thalmann
Jacques Schoeffler, Caracas, Venezuela, S. A.
H. de Cizancourt, Florent H. Bailly, Arnold F. Parr
James Albany Sinex, Jr., Wichita Falls, Tex.
Ellen Posey Bitgood, Oscar E. Gram, Robert C. Curd
Henry Crosby Stetson, Cambridge, Mass.
Kirtley F. Mather, Marland P. Billings, Robert R. Shrock
Bruce Harry Stinear, Melbourne, Victoria, Australia
H. G. Raggatt, W. D. Mott, M. Ongley
Donald Alfred Taylor, Caracas, Venezuela, S. A.
Norman E. Weisbord, Frank L. LeRoy, P. P. Conrad
Robert William Tesch, Jr., Fort Worth, Tex.
C. E. Yager, E. A. Wahlstrom, Peter P. Gregory
Hugh Miller Thralls, Tulsa, Okla.
R. W. Mossman, G. H. Westby, A. J. Barthelmes
Edwin Van den Bark, Midland, Tex.
L. H. Thawley, M. H. Steig, J. A. Jorgensen
Hendrik Willem van de Putte, Caracas, Venezuela, S. A.
Frank L. LeRoy, George W. Dawson, P. P. Conrad
Boris D. Vishanoff, South Pasadena, Calif.
Frank W. Bell, Guy E. Miller, Dewitt E. Taylor
Franklin Alton Wade, Oxford, Ohio
Joseph T. Singewald, Jr., Charles F. Passel, Milton W. Corbin
Fred R. Waldron, Denver, Colo.
N. W. Bass, Max Steineke, William G. Pierce
Cecil Lester Walker, Craig, Colo.
W. S. McCabe, M. D. Hubley, C. L. Larson
Robert Y. Walker, Jr., Abilene, Tex.
Ernest R. Lilley, Charles H. Dickerson, Frank B. Conselman

Dale Wallington, Abilene, Tex.
Joseph E. Morero, Willard F. Bailey, Riley G. Maxwell
James W. Watson, Jr., Lake Charles, La.
Wallace L. Wilgus, Frederic B. Loomis, Jr., Stanley R. Say
J. Frank West, Lake Charles, La.
Henry V. Howe, C. Lathrop Herold, James B. Dorr
Milton Thompson Whitaker, Los Angeles, Calif.
Graham B. Moody, Harvey W. Lee, Peter H. Gardett
Bradford Willard, Bethelehem, Pa.
S. H. Cathcart, Charles R. Fettke, R. E. Sherrill
Clarence William Witt, Wichita, Kan.
L. H. Lukert, M. C. Roberts, W. Morris Guthrey

FOR ASSOCIATE MEMBERSHIP

Charles Walter Allen, Los Angeles, Calif.
John P. Buwalda, Robert P. Sharp, Chester Stock
Darrell Guy Fallen Bailey, Caracas, Venezuela, S. A.
Joseph M. Patterson, R. B. Wheeler, V. C. Illing
Vernon Roy Baker, Boulder, Colo.
Warren O. Thompson, W. Warren Longley, John R. Hayes
John Allen Bauchman, Seguin, Tex.
John R. Sandidge, Ellis W. Shuler, Claude C. Albritton, Jr.
Joe Beard, Wichita Falls, Tex.
George P. Hardison, H. R. Hauptman, Jr., John R. Gisburne
John D. Bloomingdale, Carlsbad, N. Mex.
William H. Allen, Herbert M. Goodman, E. F. Schramm
John Samuel Bradley, Denver, Colo.
J. Harlan Johnson, W. S. Levings, F. M. Van Tuyl
John Henry Brunel, Golden, Colo.
J. Harlan Johnson, W. S. Levings, F. M. Van Tuyl
Graham Singleton Campbell, Denver, Colo.
E. L. Lucas, Alex W. McCoy, III, Carl A. Moore
Don Forrest Carlos, Houston, Tex.
Wayne V. Jones, L. R. Laudon, John C. Frye
William Horace Carter, Midland, Tex.
Leroy T. Patton, Raymond Sidwell, M. A. Stainbrook
Thomas Augustus Chandler, Austin, Tex.
F. L. Whitney, Hal P. Bybee, G. K. Eifler, Jr.
John Judson Chapman, Clyde, N. C.
J. Harlan Johnson, W. S. Levings, F. M. Van Tuyl
Jay W. Clampitt, Oklahoma City, Okla.
A. R. Denison, Jess Vernon, C. R. Sullivan
Alice May Corson, Brooklyn, N. Y.
John M. Lovejoy, R. S. McFarland, R. A. Stehr
Robert Edward Covington, Chicago, Ill.
F. M. Van Tuyl, Warren O. Thompson, W. S. Levings
Charles Lynwood Cox, Jr., New Orleans, La.
H. V. Howe, H. N. Fisk, Richard J. Russell
John Rowland Cox, Wichita, Kan.
K. E. Adams, V. C. Scott, F. J. Pettijohn
Louis Dempsey Cross, Dallas, Tex.
Frederick A. Burt, William L. Russell, S. A. Lynch

Robert Henderson Cross, Baton Rouge, La.
Richard Joel Russell, Harold N. Fisk, Chalmer J. Roy
Dean Lewis Cummins, Battle Creek, Mich.
Lewis B. Kellum, K. K. Landes, A. J. Eardley
Thomas Charles Danie, Jr., Hondo, Tex.
W. M. Winton, Clarence M. Sale, Leo Hendricks
David Chandler Davis, Billings, Mont.
Joseph L. Borden, Loris J. Fulton, James G. Mitchell
Ida Marie Dobler, Los Angeles, Calif.
Edward C. H. Lammers, Herschel L. Driver, W. P. Winham
Donald Davidson Dodge, Jr., Wichita, Kan.
Vernon C. Scott, W. T. Thom, Jr., K. E. Adams
Melvin H. Dodson, Mangum, Okla.
E. L. Lucas, V. E. Monnett, Carl A. Moore
John Harrah Douglass, Caracas, Venezuela, S. A.
Thomas C. Wilson, Geoffrey W. Crickmay, Robert H. Robie
James B. Duff, Dallas, Tex.
Frank A. Schultz, Ellis W. Shuler, Claude C. Albritton, Jr.
Virgle Lee Easterwood, Golden, Colo.
J. Harlan Johnson, F. M. Van Tuyl, W. S. Levings
Paul Lowry Elliott, Los Angeles, Calif.
Peter H. Gardett, R. W. Clark, Gordon R. Bell
Walter S. Fees, Jr., Casper, Wyo.
James H. Page, W. G. Olson, L. R. Laudon
Stanley Parkins Fisher, Jr., New Brunswick, N. J.
E. L. Lucas, V. E. Monnett, Carl A. Moore
Hewitt Bates Fox, New Orleans, La.
H. Gordon Damon, Hal P. Bybee, Fred M. Bullard
James Buford Fuller, Houston, Tex.
Carleton D. Speed, Jr., Frank G. Evans, M. R. Spahr
Clement Enos George, III, Midland, Tex.
Hal P. Bybee, G. K. Eifler, Jr., John T. Lonsdale
Patricia Ann Glover, Newton, Kan.
C. G. Lalicker, John C. Frye, L. R. Laudon
Jerald Melvin Goldberg, Dallas, Tex.
Ellis W. Shuler, S. M. Aronson, Claude C. Albritton, Jr.
Wayne Calvin Granger, Emporia, Kan.
L. R. Laudon, John C. Frye, C. G. Lalicker
Arthur James Gude, III, Golden, Colo.
J. Harlan Johnson, F. M. Van Tuyl, W. S. Levings
Robert J. Haas, Jr., Mt. Pleasant, Mich.
G. M. Ehlers, K. K. Landes, A. J. Eardley
Richard Frederick Hagemann, Denver, Colo.
J. Harlan Johnson, F. M. Van Tuyl, W. S. Levings
Roy Eugene Hanson, Carlsbad, N. Mex.
Wilson M. Laird, H. M. Goodman, A. C. Trowbridge
H. Warren Hartsough, Lakewood, Ohio
Walter Johnson, W. L. McCloy, Jr., John P. Smoots
James Francis Healy, Jr., Grand Rapids, Mich.
Edward J. Baltrusaitis, Max W. Ball, Kenneth K. Landes
Forrest A. Hewitt, Jackson, Miss.
J. William Schmotzer, Charles W. Sternberg, Barney C. McCasland, Jr.

Stephen Curtis Hinshaw, Lawrence, Kan.
C. G. Lalicker, L. R. Laudon, R. C. Moore
Robert Leslie Hoss, Houston, Tex.
Harry H. Power, Don L. Frizzell, John O. Barry
Wallace Frank Huey, Dallas, Tex.
T. R. Shugart, E. J. Handley, W. W. Newton
E. Carter Hutchinson, Denver, Colo.
Eugene B. Waggoner, Dart Wantland, Ross L. Heaton
James Garey Joyce, Iago, Tex.
Fred M. Bullard, G. K. Eifler, Jr., F. L. Whitney
William Bernard Kalhoefer, Midland, Tex.
Ralph D. Chambers, George R. Gibson, Cary P. Butcher
Kenneth Winfield Keene, Lawrence, Kan.
L. R. Laudon, C. G. Lalicker, John C. Frye
M. Herbert Lloyd Keener, Norman, Okla.
Keith M. Hussey, V. E. Monnett, E. L. Lucas
Virgil John Kennedy, Belleville, Ill.
H. W. Scott, J. L. Hough, Harold R. Wanless
Billy Ford Latch, Hutchinson, Kan.
R. Lee Hunter, Don B. Gould, Leonard Latch
Philip Linwood Lawrence, New Bedford, Mass.
L. W. LeRoy, W. S. Levings, F. M. Van Tuyl
Ralph Willard Lawson, Ames, Iowa
Chalmer J. Roy, Raymond E. Peck, M. G. Mehl
William Robert Ledbetter, Beaumont, Tex.
S. A. Lynch, Frederick A. Burt, William C. Rasmussen
Ambrose Lee Lyth, Jr., Austin, Tex.
H. B. Stenzel, Samuel S. Goldich, John T. Lonsdale
Paul Joseph Lewis, Newark, Ohio
L. R. Laudon, C. G. Lalicker, Raymond C. Moore
Herman Loeb, Shreveport, La.
C. C. Clark, L. H. Meltzer, W. H. Spears
Bernard Walden Lynch, Urbana, Ill.
Harold R. Wanless, J. L. Hough, H. W. Scott
Carol Nancy Macha, Ann Arbor, Mich.
K. K. Landes, A. J. Eardley, George V. Cohee
Donald Macomber, Jr., Brunswick, Maine
Joseph A. Cushman, Kirtley F. Mather, Preston E. Cloud, Jr.
Cecilia Martin, Caracas, Venezuela, S. A.
K. F. Dallmus, Pedro J. Bermudez, Harry W. Anisgard
Robert Franklin Mathews, San Antonio, Tex.
F. L. Whitney, Hal P. Bybee, Fred M. Bullard
Jack Hairston McCollum, Meridian, Miss.
E. F. Richards, T. G. Andrews, G. R. Schoonmaker
Robert Clyde McFadden, Jr., Midland, Tex.
Robert L. Clarke, S. C. Giesey, J. A. Jorgensen
Donald Montford Eastman McLarty, Rawlins, Wyo.
Raymond D. Sloan, George R. Downs, William A. Newton
David Basye Meisenheimer, Jefferson, Tex.
S. A. Lynch, W. L. Russell, Frederick A. Burt
Gerald Conroy Merket, Midland, Tex.
Henry J. Morgan, Jr., H. V. Tygrett, George H. Norton

Richard Fastabend Meyer, Scarsdale, N. Y.
Kirtley F. Mather, Marland P. Billings, Preston E. Cloud, Jr.
Leonard A. Murphy, Boulder, Colo.
Warren O. Thompson, John R. Hayes, W. Warren Longley
Clifton Jerry Nolte, Oklahoma City, Okla.
Carl A. Moore, V. E. Monnett, Keith M. Hussey
Jeff Dorris Nunnally, Shreveport, La.
Keith M. Hussey, V. E. Monnett, Carl A. Moore
Lawrence Ogden, Maryville, Mo.
A. N. Murray, W. H. Twenhofel, C. V. Sidwell
Eugene Robert Orwig, Jr., Van Nuys, Calif.
M. N. Bramlette, Cordell Durrell, John C. Crowell
Donald Eugene Owen, Emporia, Kan.
C. G. Lalicker, L. R. Laudon, Raymond C. Moore
James Durwood Pate, Oklahoma City, Okla.
Don L. Hyatt, Carl T. Anderson, W. J. Hilseweck
Jesse Walter Pennington, Van Buren, Ark.
V. E. Monnett, Charles E. Decker, James E. Lewark
Richard Frank Peterson, Houston, Tex.
A. H. Bleyberg, F. E. Mettner, George H. Clark
Billy Joe Pevehouse, Eunice, N. Mex.
Raymond Sidwell, W. I. Robinson, Leroy T. Patton
Louise M. Powell, Kermit, Tex.
A. J. Eardley, K. K. Landes, George V. Cohee
George Haskell Rainey, Norman, Okla.
E. L. Lucas, V. E. Monnett, Carl A. Moore
Warren Gardner Reed, Jr., Shreveport, La.
Chalmer J. Roy, H. N. Fisk, Richard J. Russell
Hendrik Karel Roessingh, Leiden, Holland
James G. Mitchell, L. T. Hart, Jerry R. Kyle
Carl Stanley Rose, Monument, N. Mex.
V. E. Monnett, Keith M. Hussey, Carl A. Moore
Walter Hille Rose, New Orleans, La.
H. Mack Cox, Gurrie R. Henson, Gordon I. Atwater
Robert V. Ruhe, Ames, Iowa
Chalmer J. Roy, A. C. Trowbridge, A. K. Miller
Elliott Davidson Sherman, Los Angeles, Calif.
Cordell Durrell, William C. Putnam, James Gilluly
Nathaniel Bert Smith, Jr., Oklahoma City, Okla.
F. A. Melton, Carl A. Moore, V. E. Monnett
Irving Lee Snider, West Jackson, Miss.
Lloyd A. Nelson, Knight K. Spooner, Charles W. Sternberg
Willard Roland Stearns, Austin, Tex.
A. O. Woodford, G. K. Eifler, Jr., R. W. Byram
William Walter Stevens, Jr., Mt. Vernon, Ill.
V. E. Monnett, Carl A. Moore, E. L. Lucas
Walter Alan Stewart, Golden, Colo.
J. Harlan Johnson, W. S. Levings, F. M. Van Tuyl
Meredith Russell Stipp, Tulsa, Okla.
A. N. Murray, R. A. Brant, Carroll V. Sidwell
Anna Frances Muhlenbruch Stucker, Fort Worth, Tex.
L. R. Laudon, John C. Frye, M. L. Thompson

Suzanne Takken, Oklahoma City, Okla.
Walter L. Moreman, F. E. Wimbish, George V. Cohee
Wentworth J. Tellington, Tulsa, Okla.
Paul C. Reed, H. N. Coryell, E. J. Handley
Gerald Frank Thornhill, Laramie, Wyo.
R. L. Kretz, L. W. Folsom, Nelson B. Potter
Robert Freeman Thurrell, Jr., Denver, Colo.
Kirtley F. Mather, Glen Ruby, Don L. Carroll
John Lewis Townley, III, Midland, Tex.
Fred M. Swain, George A. Thiel, Robert P. Sharp
George Gilbert Tubb, Lake Charles, La.
W. R. Canada, Bert C. Timm, Howard L. Tipsword
Fisher Lee Van Arsdale, Shreveport, La.
W. E. Wallace, Jr., Brame Womack, L. F. Fischer
Lindell Howard Van Dyke, Champaign, Ill.
Jack L. Hough, H. W. Scott, Harold R. Wanless
Charles Winfield Van Eaton, III, Oklahoma City, Okla.
Garrett A. Muilenburg, Roger H. Cowie, F. A. Graser
Lachlan M. Vass, Jr., Lafayette, La.
James S. Kirkendall, F. B. Stein, E. M. Ross, Jr.
Edward C. Veigel, Lima, Peru, S. A.
J. Donald MacGregor, L. A. Smith, J. C. Sproule
Wilton Canova Vercellino, Houston, Tex.
S. A. Lynch, W. L. Russell, W. C. Rasmussen
Leo Vesenmeir, Jr., Dallas, Tex.
Augustus Bart Brown, Claude C. Albritton, Jr., George W. Pirtle
John Gordon Voight, San Antonio, Tex.
S. A. Lynch, William C. Rasmussen, Frederick A. Burt
William Voigt Wade, Midland, Tex.
E. F. Schramm, A. L. Lugn, E. E. Lindeblad
Abe W. Wagner, Jr., Houston, Tex.
Frederick A. Burt, William C. Rasmussen, S. A. Lynch
James Louis Walker, Denver, Colo.
Warren O. Thompson, W. Warren Longley, John R. Hayes
Rolf Charles Walther, Caripito, Venezuela, S. A.
Douglas D. Howard, J. H. Sawyer, Gordon Ashbridge White
Loren L. Ware, Moore, Okla.
R. M. Gawthrop, G. H. Laughbaum, W. H. Wynn
Joseph Dominic Watzlavick, Schulenburg, Tex.
N. N. Zirbel, A. W. Bunsen, T. I. Harkins
William W. Webber, Dallas, Tex.
Ellis W. Shuler, Frank E. Kendrick, Claude C. Albritton, Jr.
Felix Howard Webster, Brookhaven, Miss.
David C. Harrell, Frederic F. Mellen, C. W. Alexander
Robert Irvin Westmacott, Nowata, Okla.
C. G. Lalicker, L. R. Laudon, R. C. Moore
Bob Owen White, Salt Lake City, Utah
George H. Hansen, J. M. Kirby, Charles B. Hunt
James Robert White, Fort Worth, Tex.
Edwin M. Rowser, D. G. Stookey, R. H. Schweers
Amos Daniel Whitten, Jr., Denver, Colo.
E. L. Lucas, Charles E. Decker, Alex W. McCoy, III

Jacob Lory Williams, III, Midland, Tex.
Addison Young, C. D. Cantrell, Jr., John W. Ruwwe
Homer C. Wilson, Jr., Kingsville, Tex.
Henry D. McCallum, Dean Metts, G. B. Gierhart
Stephen Samuel Winters, Newark, N. J.
Norman D. Newell, Marshall Kay, Charles H. Behre, Jr.
Carroll A. Wood, Granada, Colo.
F. M. Van Tuyl, J. Harlan Johnson, W. S. Levings
Jerome J. Wright, Wichita, Kan.
J. M. Kirby, Julian W. Low, L. C. Hay
Estey R. Youngblood, Jr., Beaumont, Tex.
L. C. Aycock, Herbert L. Durgan, Richard H. Hopkins
John Milton Zeigler, Fort Pierce, Fla.
Warren O. Thompson, John R. Hayes, W. Warren Longley
Edward J. Zeller, Lawrence, Kan.
Raymond C. Moore, L. R. Laudon, John C. Frye

FOR TRANSFER TO ACTIVE MEMBERSHIP

Walter Herbert Alexander, Jr., College Station, Tex.
S. A. Lynch, Frederick A. Burt, William L. Russell
Raymond Joseph Berryman, Bakersfield, Calif.
Glen B. Gariepy, E. H. Vallat, Horace D. Thomas
Roland White Carter, Tulsa, Okla.
A. J. Barthelmes, C. E. McClure, J. L. Gartner
Marjorie Fuqua, Houston, Tex.
Perry Olcott, Edward D. Pressler, J. Ben Carsey
Kenneth Work Germond, Dallas, Tex.
F. E. Heath, A. M. Lloyd, Robert B. Totten
Raymond M. Hart, Tulsa, Okla.
L. Murray Neumann, M. W. Fuller, George A. Musselman
Ralph Carroll Holmer, Golden, Colo.
C. A. Heiland, W. S. Levings, F. M. Van Tuyl
Keith Frederick Huff, Lima, Peru, S. A.
Axel A. Olsson, L. H. Smith, J. C. Sproule
Nooe William Johns, Natchez, Miss.
G. W. Gulmon, F. E. Turner, Bruce Scrafford
Bernhard Kummel, Austin, Tex.
John T. Lonsdale, H. B. Stenzel, Virgil E. Barnes
David Kemp Langford, Wichita Falls, Tex.
Paul E. M. Purcell, Joseph J. Maucini, Ellen Posey Bitgood
Wendell Leslie Lewis, Houston, Tex.
Ray C. Lewis, C. H. Sample, Dan E. Boone
Alfred Norman McDowell, Caracas, Venezuela, S. A.
G. Zuloaga, K. F. Dallmus, John H. Regan
Georges Pardo, Summit, N. J.
Hollis D. Hedberg, Augustin Pyre, E. S. Bleecker
Travis J. Parker, College Station, Tex.
S. A. Lynch, Frederick A. Burt, William L. Russell
Thomas Gibson Payne, Washington, D. C.
Carle Dane, William Pierce, Arthur Baker
Francis Ward Perrin, Sudan, Tex.
Barthold William Sorge, John W. Daly, V. G. Feather

Harold Bell Renfro, Tulsa, Okla.
A. N. Murray, W. H. Twenhofel, Bryan D. Beck, Jr.
Elgean Shield, Santa Anna, Tex.
Hal P. Bybee, Jack A. Crichton, H. J. Gruy
William Russell Sype, Tulsa, Okla.
R. Clare Coffin, Garvin L. Taylor, R. A. Weingartner
Wilfred Bonno Tapper, Duncan, Okla.
E. A. Wendlandt, A. C. Wright, Roy Hazzard
Harris Peyton Wells, Jr., Corsicana, Tex.
C. H. Sample, Phil F. Martyn, Joseph M. Wilson
William Harris White, New Orleans, La.
A. C. McFarlan, Harold N. Hickey, William L. Effinger
Homer Olwin Woodbury, Denver, Colo.
N. W. Bass, J. M. Kirby, H. T. Richardson

---

## REGIONAL MEETING, PITTSBURGH, OCTOBER 4–9, 1948

The Pittsburgh Geological Society will be the host for an Appalachian regional meeting of the A.A.P.G., at Pittsburgh, Pennsylvania, on October 4 and 5, followed by a field trip on October 6–9. Headquarters for the two days of technical sessions will be the William Penn Hotel. The general subject of Appalachian geology will be covered by authorities on the region. The program is to be strictly regional in character, concentrating on geological subject matter and technical discussion, with a minimum of business and entertainment. Following the field trip, a session at Bradford, Pennsylvania, will be devoted to secondary recovery. A reasonable registration fee will be charged.

A postcard inquiry has been mailed this month to each member. Prompt replies are requested so that the committees at Pittsburgh may make adequate arrangements. A copy of the card is here published for information only, not for return.

(Postcard mailed to members)

PRELIMINARY ANNOUNCEMENT-MID-YEAR MEETING

A mid-year regional meeting of the American Association of Petroleum Geologists will be held in Pittsburgh, Pennsylvania, October 4 to 9, 1948.

There will be a two-day technical session followed by a three-day field trip. A post-convention session on secondary recovery will be held in Bradford, Pa., on Friday evening (last day of field trip).

Are you coming? Please check the boxes on the attached postal card and drop it in the mail immediately. The various committees must make commitments soon.

You will receive detailed information in future announcements.

I plan to attend the technical sessions ..... ☐
I plan to attend the field trip ..... ☐
I plan to attend conference on secondary recovery ..... ☐
I will need hotel reservations for myself and _____ persons.

_____
Name and Address

An outline of field-trip itinerary and chronology follows.

Wednesday, October 6: First day of field trip. The group will travel by bus from Pittsburgh to Harrisburg, a distance of 215 miles. The caravan will leave the Pennsylvania Turnpike at Somerset and travel to vantage points such as Grand View Point on the Allegheny Front.

Thursday, October 7: Harrisburg, Pa., to Rochester, N. Y., about 250 miles. The trip is

being logged by Pennsylvania and New York Geologists. The Rochester Museum will be open that evening.

Friday, October 8: Part (1) Rochester to Niagara Falls on Route 31, about 85 miles. Part (2) Niagara Falls to Bradford, Pa., in time for a banquet. Part (3) conference on Secondary Recovery at Bradford, Friday evening.

PITTSBURGH GEOLOGICAL SOCIETY
OFFICERS, 1948–1949

President: John T. Galey
Vice-president: W. B. Robinson
Treasurer: S. S. Galpin
Secretary: J. C. Patton

COMMITTEE CHAIRMEN FOR A. A. P. G. MIDYEAR MEETING

General chairman: H. R. Brankstone
Program committee: John T. Galey
Field-trip committee: George C. Grow
General arrangements committee: Fordyce C. Hauber
Finance committee: S. S. Galpin
Publicity committee: W. B. Robinson

---

## JOINT ANNUAL MEETING
## JEFFERSON HOTEL, ST. LOUIS, MARCH 14–17, 1949
## AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
## SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS
## SOCIETY OF EXPLORATION GEOPHYSICISTS

The joint annual meeting of the three petroleum exploratory societies will be held at the Jefferson Hotel, St. Louis, Missouri, on March 14, 15, 16, and 17, 1949.

The official form of "Application for Housing Accommodations" is being mailed to each member this month (July). The following copy is published here for information, not for return.

All requests for hotel rooms should be made by returning the attached form to the American Association of Petroleum Geologists, Hotels Reservation Bureau, 1420 Syndicate Trust Building, St. Louis 1, Missouri. Requests for reservations should be made as far in advance of February 14, 1949, as possible, and should contain all information requested on the attached form. Receipt of requests will be acknowledged and filed in order of receipt at the Housing Bureau. Actual assignments will be made in the various hotels and confirmations will be mailed about 60 or 90 days prior to the convention. Members who request reservations, but later find they can not attend, should notify the Hotels Reservation Bureau without delay. Blocks of rooms will not be reserved. All rooms must be reserved in the names of individuals.

This notice is being mailed simultaneously to the members of the three societies. Officers, representatives, and committee members, particularly, are requested to reply promptly.

The executive committees of the societies constitute the committee for arrangements and program. Certain convention chairmen will be named and details will be announced later. As no local group is sponsoring this meeting, special entertainment features of recent annual meetings will be omitted. Entertainment is to be on a pay-as-you-go basis. A reasonable registration fee will be charged.

THE EXECUTIVE COMMITTEES

Tulsa, Oklahoma
July 15, 1948

---

(This is a COPY of the form being mailed to members)

## APPLICATION FOR HOUSING ACCOMMODATIONS, ST. LOUIS, MO.

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS—MARCH 14–17, 1949

For your convenience in making hotel reservations for the coming joint meeting of the American Association of Petroleum Geologists, the Society of Economic Paleontologists and Mineralogists, and the Society of Exploration Geophysicists, March 14–17, 1949, in St. Louis, hotels and their rates are listed below. Use the form at the bottom of this page, indicating your first, second and third choice. Because of the limited number of single rooms available, you will stand a much better chance of securing accommodations if you request calls for rooms to be occupied by two or more persons. All reservations must be cleared through the housing bureau. ALL REQUESTS FOR RESERVATIONS MUST GIVE DEFINITE DATE AND HOUR OF ARRIVAL AS WELL AS DEFINITE DATE AND APPROXIMATE HOUR OF DEPARTURE, ALSO NAMES AND ADDRESSES OF ALL PERSONS WHO WILL OCCUPY RESERVATIONS REQUESTED *must* BE INCLUDED.

| *Hotel* | *For One Person* | *For Two Persons* | | *2-Room Suites* |
|---|---|---|---|---|
| | | *Double Bed* | *Twin Beds* | *Parlor and Bedroom* |
| BALTIMORE | 2.75–3.50 | 3.75– 4.50 | 4.00– 5.00 | |
| CLARIDGE | 3.00–4.00 | 4.00– 6.50 | 5.00– 6.50 | 10.00 & Up |
| *DESOTO | 2.75–7.00 | 4.00– 7.00 | 6.00–12.00 | 10.50–12.00 |
| *JEFFERSON | 3.50–6.00 | 5.00– 7.00 | 7.00– 8.00 | 14.00–22.00 |
| *LENNOX | 3.25–6.00 | 5.00– 6.50 | 6.00– 8.00 | 11.00 |
| *MAJESTIC | 2.25–3.50 | 3.00– 4.00 | 5.00 | |
| *MARK TWAIN | 3.00–3.50 | 4.50– 5.00 | 5.00– 5.50 | |
| *MAYFAIR | 3.25–7.00 | 5.00– 8.00 | 6.00– 8.00 | 11.00 & Up |
| MELBOURNE | 3.50–6.00 | 5.50– 6.50 | 6.00– 8.50 | 12.00–15.50 |
| SHERATON | 3.50–6.00 | 5.25–10.00 | 5.50–11.00 | 8.50–15.00 |
| *STATLER | 3.50–6.00 | 5.25– 8.00 | 7.25–10.00 | 16.00–19.00 |

* Downtown

In the event that the hotel room rate structure is changed prior to the above convention, these rates will be changed accordingly.

ALL RESERVATIONS MUST BE RECEIVED PRIOR TO: February 14, 1949

American Association of Petroleum Geologists
Hotels Reservation Bureau,
1420 Syndicate Trust Building,
St. Louis 1, Mo.

Please reserve the following accommodations for the: Joint convention of the A.A.P.G., S.E.P.M., and S.E.G., in St. Louis, Missouri, on March 14–17, 1949

Single Room..... Double Bedded Room..... Twin Bedded Room.....
2 Room Suite..... Other Type of Room.....
Rate: From $..... to $.....

First Choice Hotel.....
Second Choice Hotel.....
Third Choice Hotel.....

Arriving at Hotel (date) ..... hour .....A.M. .....P.M. .....
Leaving (date) ..... hour .....A.M. .....P.M. .....

THE NAME OF EACH HOTEL GUEST MUST BE LISTED. Therefore, please include the names of *both* persons for *each* double room or twin bedded room requested. Names and addresses of all persons for whom you are requesting reservations and who will occupy the rooms asked for:

.....
.....
.....
.....

(Individual Requesting Reservations)
Name .....
Address .....
City and State .....

*If the hotels of your choice are unable to accept your reservation the Housing Bureau will make as good a reservation as possible elsewhere providing that all hotel rooms available have not already been taken.*

## OUR NATIONAL RESPONSIBILITY AS GEOLOGISTS[1]

A. I. LEVORSEN[2]
Stanford University, California

The world is still frantically striving for a satisfactory peace and from all indications will continue to strive for some years to come. As one of the principal ingredients of the present unrest, we find petroleum—not as the oil which smooths the waters, but rather as the key mineral substance essential to every nation which would maintain its position as a major world power. My thesis is, that, because we are geologists, skilled in the discovery of new oil and gas fields, we have had thrust upon us greater responsibilities than any of us ever believed possible—responsibilities second only to those which have been thrust upon the atomic scientists.

No one will deny that enough oil and gas, both discovered and undiscovered, exists throughout the world to supply the world with all of its needs for generations. The irregular geographic distribution of the world's reserves, however, is such as to give cause for concern as to their future availability. This is particularly true of the great petroleum resources of the Near East—Iran, Iraq, Kuwait, and Saudi Arabia. If control of these reserves should fall into the hands of an aggressor nation, that nation would have the power to become the master of three continents—Asia, Africa, and Europe—with nearly 2 billion people. The reason is that petroleum is essential to both peace and war and can be supplied to friendly nations and withheld from unfriendly countries by whomever controls its production.

The Near East reserves, now owned by British and American interests, constitute the greatest single economic and political prize in the world to-day. They adjoin Russia and are located within countries controlled by relatively weak governments. It is but natural, therefore, in the world struggle for power, that Russia should cast envious eyes in their direction.

Because of the uncertainty of the continuous availability of these reserves to the United States, we dare not become dependent upon them for our supply. The same danger to a lesser extent exists with regard to petroleum imports from other foreign sources—because, as demonstrated in the recent war, ocean-borne supplies can not be depended upon in a war emergency. Nor can we hope to develop fuels in substantial quantities in a short time from substitute materials such as coal, oil shale, or bituminous sands, because this is a long-term program. There is but one answer now for the United States, and that is, keep the wildcatter going!

The modern wildcatter is dependent almost completely on the application of the earth sciences such as geology, geophysics, and geochemistry, and on engineering principles to guide him in his search for oil and gas. Discovery is becoming more complex and more expensive, and every conceivable means is employed to increase its chances of success. An adequate and continuous supply of crude oil has become the critical element in the American petroleum industry, and the wildcatter bears the same relation to gasoline in the petroleum industry that the farmer bears to flour in the food industry—both are indispensable.

One of the most significant trends in recent years has been the change in the role of the geologist within the oil industry. Where he used to be the professional adviser to the wildcatter, he is now in executive positions in nearly all oil companies and is charged with the finding of the oil. Instead of recommending to the executives where to explore, now he

[1] Read before the Association at Denver, Colorado, April 27, 1948, after receiving the Powers Memorial Medal.

[2] Dean, School of Mineral Sciences, Stanford University.

decides where to go and how to do it. This change in his status reflects the critical importance of crude-oil supply to the industry and it places the full responsibility of discovery on the geologist. More often than not the modern wildcatter *is* a geologist, either as the president, vice-president, or manager of exploration of an oil company, as an operating partner in the venture, or as the owner of the operation. His thinking takes on an entirely new outlook—he has all of a sudden come of age. This is the New Look, geologically speaking!

A recent letter from United States Senator Henry Cabot Lodge, Jr., contained this arresting statement: "Petroleum, as you know, is absolutely essential to our survival as a nation." We *must* have an ample supply, available at all times, and for any emergency. We do not have it in sight at the present moment. It is our job as geologists to assure such a supply. Each of us might ask himself the serious question, "What are we going to do about it?" The people of the United States expect an answer from us because we alone represent the science which is directly concerned with minerals, rocks, and the earth, and with the occurrence of oil and gas within the earth. There is no one else to whom they can turn for an answer.

One thing is certain—we are not going to find oil if we give up without trying. Oil is like fishing—one does not catch fish with his hook out of the water, and oil is not found if the drill is not kept going. A favorable economic climate is one of the essentials of keeping the drills going. Another is a solid geological conviction that oil is to be found if the drills are kept going. This requires a lot more geological vigor than does the conclusion we are about to run out of oil discoveries. The industry has always explored at the edge of its knowledge and the fact that some in the industry see little favorable ground for future prospecting is nothing new.

The wildcatter operates from a platform of optimism. When the prices are low and the geologists condemn a region, he either stacks his tools or moves on to other areas. The Rocky Mountain province is a good example of what happens to a region when gloom and pessimism descend. Only a few years ago it was given up generally as a potential producing region by most operators. Geologists, land men, and wildcatters left the region in droves, and only skeleton organizations remained. The sad fact is, however, that because orthodox opinion gave it up as a potential producing region, this had nothing to do with the amount of oil present—it merely delayed its discovery. As discoveries finally were made, hopes rose, and back they all rushed to make it again one of the favored areas for wildcatting. How many other regions in the United States are now on the shelf because orthodox geological opinion gave up too soon?

This all points to one of the fundamental weaknesses of petroleum geology—we do not have a solid enough foundation upon which to judge objectively the petroleum possibilities of new or partially explored regions. Yet it is there that we expect to discover our most important future reserves. The principles of petroleum occurrence as applied to these partially explored regions deserve our most serious thinking. The program of our Research Committee needs to be carried out. We need to get going!

There is one service to society which we might perform as an organization. This is for the American Association of Petroleum Geologists to take on the responsibility of making some sort of an annual survey of the relative amount of our undiscovered petroleum resources. As the result of each year's drilling, some areas appear to be more favorable for discovery while others appear to be less favorable. Dry holes do not always condemn—they often indicate underground conditions which favor further prospecting. The discovery of some oil fields points to the discovery of many more and opens up our thinking to greatly enlarged opportunities. A representative committee of the Association might survey the important changes and announce their results at the time of the annual meeting. Such a survey would be comparable and parallel with that made of the known underground reserve each year by a committee of the American Petroleum Institute. These

known reserves, however, are but a working stock, whereas the extent of the undiscovered reserves is the crux of the entire petroleum reserve picture. Such a survey would be of the utmost value to our national planning, law-making, and safety and would provide the public with an authoritative objective statement of the current status of our petroleum prospects.

In addition, therefore, to the job of discovering oil and gas for ordinary peaceful uses, petroleum geologists and geophysicists now have the grave responsibility of maintaining an adequate supply within the United States of one of the most essential and important of all war materials. Our national supplies of oil and gas are completely dependent upon petroleum geologists and geophysicists. We have suddenly become the keystone in the structure of our whole national safety. There is no retreat from our position. To go forward, however, requires the best brains and thinking in America. May we measure up!

---

## REMARKS OF NEW HONORARY MEMBER[1]

HUGH D. MISER[2]
Washington, D. C.

*President Dobbin, Mr. Dott, Members and Guests of the American Association of Petroleum Geologists:*

My hand and heart have just received from you, as a token of your esteem and friendship, honorary membership in the American Association of Petroleum Geologists, the world's best and biggest organization of geologists. For this great honor, kindly and generously bestowed, and for all the kind words here said about me I thank you most humbly from the bottom of my heart. At this moment my ability to cogitate has about ceased. I am practically speechless. I am at a loss to find words other than *Thank You.* I wish, however, to remind you that I shall be an honorary member for a long time if I live as long as my great-grandfather, George Miser, of Pennsylvania and Tennessee. His span of life refuted the oft-repeated saying that "The first hundred years are always the hardest." One day, while he was doing his usual chores in the barnyard, a bull attacked him and gored him to death at the age of 105 years.

On this occasion there would seem to be no profit to be gained from any review by me of my geologic activities since I left my home town of Pea Ridge, Arkansas, 40 years ago. You are familiar with my published papers and reports. Also, you are familiar with the 400 reports written by Fuel Section authors of the United States Geological Survey in the past 20 years when I was chief of that section. Especially familiar are you with the Geological Survey's preliminary maps and charts of the oil and gas investigations series. You and others have obtained and used 80,000 copies of the 113 maps and charts that have been published in the past 5 years. So numerous and big are they that a complete set placed end to end and pasted together, would make a sheet of paper 500 feet long. In addition, the individual maps and charts may be hard for some persons to hold, read, and file. This form of publication, I am, however, happy to state, permits the prompt release of results of the Survey's oil and gas investigations. We could find no other way to accomplish this amid the maze of red tape in Washington.

[1] Read before the Association at Denver, Colorado, April 27, 1948, after receiving honorary membership.

[2] Geologist, United States Geological Survey.

While the personnel of the Fuels Section were performing faithfully and energetically a wonderful record of public service in the past 20 years, I kept busy in my own way, doing a number of things. One of these was using a blue pencil on the 400 manuscript reports of Fuel Section authors, and on 400 other reports from other sources. Another thing I did was to hold and join conferences at any place and any time. Also, I have traveled far and often to Arkansas and nearly all the surrounding states. Mixed with such activities and travel I have told stories in spite of incredulity of listeners. Since last summer I have been free of administrative work. I have read not a single official manuscript. I have won freedom from most of the Washington red tape. I am thus living in a new environment of freedom—most of the time in Oklahoma. My principal job is the preparation of a new geological map of Oklahoma—a cooperative project of the Oklahoma Geological Survey, oil-company geologists, and the United States Geological Survey.

Work and hope characterize the lives of geologists. We seek and acquire new knowl edge, and our application thereof means new things, more jobs, and advancement in human welfare. We do not work alone. The things that we accomplish represent the efforts of many. My good fortune has been to be associated with many fellow workers at all times. To all these I am deeply indebted and grateful for cooperation and assistance. In addition my endeavors have been enthusiastically and helpfully supported by Mary Kate Miser, the better half of the Miser household. Her encouragement and cooperation have made possible all the endeavors in which I have participated.

To you, who are my friends, I again extend my grateful thanks for bestowing upon me the great honor of this occasion. Whether or not I shall live as long as my great-grandfather Miser, I shall always treasure in my heart and hands this kind token of your friendship and esteem and I shall always recall happily the memories of this occasion.

---

## WEST TEXAS GEOLOGICAL SOCIETY FIELD TRIP, OCTOBER 29–31

A field conference sponsored by the West Texas Geological Society is scheduled for October 29, 30 and 31 in the Big Bend region of southwest Texas. The specific areas to be studied are: Green Valley, Solitario, Limpia Canyon and the Barilla Mountains. The purpose of this conference is to study Upper Cretaceous and Tertiary rocks, the geologic history of which is represented by a complete gap in the Permian basin. This conference should be of special interest to Gulf Coast geologists as it will afford the opportunity of examining beds contemporaneous with Gulf Coast producing strata.

The geological studies for this conference were made by the Texas Bureau of Economic Geology.

Leaders of the conference will be: Professor S. S. GOLDICH, University of Minnesota; JOHN T. LONSDALE, director of the Texas Bureau of Economic Geology; Professor G. K. EIFLER, JR., Department of Geology, University of Texas; and R. K. DEFORD, Argo Oil Corporation, Midland, Texas.

Details of assembly and registration as well as hotel accommodations will be furnished later.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1382-1384, 1 FIG.

# MEMORIAL

## GEORGE ELMER ABERNATHY

(1888–1948)

On February 6, 1948, Doctor G. E. Abernathy, geologist in charge of the Southeast Kansas Field Office, State Geological Survey of Kansas, Pittsburg, died in a St. Louis hospital. Thus Kansas lost a most valuable exponent of her economic geology, for Dr. Abernathy was extremely well informed concerning the geology of and the application of engineering to the mineral resources of a large area. His community and State lost a valuable citizen, and many of us lost an irreplaceable co-worker and friend.

George Elmer, the son of James Luther and Laura Alice Abernathy, was born at Willow Springs, Missouri, on August 4, 1888. At the age of sixteen he graduated from the Willow Springs Military Academy, and he then became superintendent of the Willow Springs electric plant which position he held for three years. In 1914 Abernathy was graduated with the B.S. degree in mining engineering from the University of Missouri School of Mines and Metallurgy, and in 1927 he received the E.M. degree from the same school after having earned the M.S. degree in mining engineering from the University of Kansas in 1925. In 1936 he took his Ph.D. degree in geology at the University of Kansas. Thus during a very active career in engineering and teaching he found time to further his academic training.

Abernathy was married to Anna Gordon in 1911 at Rolla, Missouri. A son, Gene Elmer, was born in 1913. Mrs. Abernathy, the son now of Eureka, Kansas, a brother, Roy E. Abernathy of Chaffee, Missouri, and two grandchildren survive him.

Dr. Abernathy's experience was unusual in scope and variety in his chosen fields. In 1907 he was millman in an experimental mine of the Utah Copper Company, Bingham Canyon, Utah. He was mine and shift boss for the Anaconda Copper Company, Butte, Montana, in 1908 and 1909. In 1911–1912 he was superintendent of precipitation and refining for Los Dos Estrellas, El Oro, Mexico. After graduating from college in 1914 he and his brother installed the Dixon Power and Light Plant at Dixon, Missouri. In 1917 Abernathy was a mine foreman for the Arizona Copper Company, Stoddard, Arizona. He was again in Butte in 1918 as mining engineer for the Butte and Superior Mining Company. In 1919–1920 he was general mine superintendent for the Chateaugau Iron and Ore Company, Lyon Mountain, New York.

In 1921 the mining engineer turned to teaching and became an assistant professor at Kansas State Teachers College, Pittsburg. He became associate professor in 1926 and professor in 1928. In 1937 his desire to become more active in advancing the mineral industries of Kansas caused him to accept the position of geologist on the staff of the State Geological Survey of Kansas. As a teacher, Professor Abernathy trained and inspired several young men for distinguished careers in engineering and earth sciences, but more important, he enthusiastically taught the fundamentals of geology to hundreds of students, many of whom became teachers and are carrying on a phase of his work.

Dr. Abernathy had the ability of balancing the dignity of his profession and accomplishments with the humility of a student earnestly seeking after the truth. As a Survey geologist his contacts with fellow workers, business tycoons, and the humblest citizens were marked with the same courtesy.

Abernathy was an inventor and held patents on several engineering designs.

This man of many professional accomplishments found time to share in the leadership of his community. He was a scoutmaster for more than two years and six scouts from his troop later became ministers. He was a Sunday-school teacher and a member of the Board of Deacons of the First Presbyterian Church, Pittsburg. He was a Mason and a member of the Order of the Eastern Star, having gone through the chairs of both the Knights Templar

GEORGE ELMER ABERNATHY

and the Eastern Star. He filled several appointments to the Grand Chapter of the Eastern Star and was Grand Representative of the Rainbow Girls from which organization he received the Grand Cross of Colors. He was a member of the Kiwanis and Lions clubs and of the Pittsburg Chamber of Commerce.

Dr. Abernathy was a member of the American Association of Petroleum Geologists,

the American Institute of Mining and Metallurgical Engineers, the Kansas Geological Society, Sigma Gamma Epsilon, Sigma Xi, and the Kansas Academy of Science. Had it not been for his untimely death Dr. Abernathy undoubtedly would have been elected a Fellow in the Geological Society of America in April. His candidacy had been approved by the membership committee and by the Council, and his name had been before the Fellows of the Society for four months without adverse comment.

Almost until the time of his death, Dr. Abernathy was busy investigating oil and gas, coal, clay, and ground-water resources as well as basic geology. He was author of several Survey bulletins and other scientific papers. Especially should be mentioned reports of his studies of the stratigraphy of the Cherokee rocks (Desmoinesian), oil and gas exploration maps and reports on Labette and Montgomery counties, various coal studies, and reports on ground water. He discovered cyclothems in the Cherokee shale.

The very remarkable cheerfulness and the fine sense of humor, among the other sterling qualities that were George Abernathy's, will be long remembered by his friends.

JOHN MARK JEWETT

Lawrence, Kansas
May 7, 1948

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 32, NO. 7 (JULY, 1948), PP. 1385-1394, 1 FIG.

# AT HOME AND ABROAD

## NEWS OF THE PROFESSION

JAN E. MULLER has resigned from the Shell Oil Company of Canada. He is a geologist on the staff of the Geological Survey of Canada, National Museum, Ottawa.

WILLARD L. MILLER, for many years with the Ramsey Petroleum Corporation, is now associated in the partnership of Miller and Stewart, Apco Tower, Oklahoma City.

RICHARD T. SHORT has left the Navarro Oil Company to join the Continental Oil Company at San Antonio, Texas.

SAM E. HILBURN is district geologist and engineer for Yarborough and Phillips Oil, Levelland, Texas.

WILLIAM E. HUMPHREY has resigned from a position as exploration geologist with the Standard Vacuum Oil Company and has accepted employment with the Phillips Venezuelan Oil Company in Caracas.

CLYDE W. ALEXANDER resigned April 1, 1948, as partner in the Dixie Geological Service, Jackson, Mississippi, and has opened a consulting office at 4100 Northview Drive, Jackson, Mississippi. His mailing address is Box 4389.

NICHOLAS A. ROSE has recently opened his office as consulting ground-water geologist at 1309 Anita Avenue, Houston. He was formerly with the Ground-Water Division of the United States Geological Survey and more recently with Lockwood and Andrews, consulting engineers.

K. WASHINGTON GRAY, who has been chief geologist in charge of exploration in Papua-New Guinea for the Australasian Petroleum Company and the Island Exploration Company, except during the war-time suspension, is returning to Anglo-Iranian headquarters, Britannic House, London. He hopes to be in England in time for the International Geological Congress in August and September.

ROLLA E. HARGRAVES has resigned his position with the Superior Oil Company. He is working for the Anderson-Prichard Oil Corporation, Wichita Falls, Texas.

RAYMOND F. MCMILLEN, formerly with the Alkay Oil Company, has joined the land and geological department of the Midstates Oil Corporation, Tulsa, Oklahoma.

T. K. KNOX is no longer with the Republic Natural Gas Company. He is engaged in independent work. His address is 3621 University Boulevard, Dallas, Texas.

M. M. MULHOLLAND has returned from Bogota, Colombia, where he was with the Tropical Oil Company. His temporary address is Point-of-Pines, Hydeville, Vermont.

---

### WYOMING GEOLOGICAL ASSOCIATION FIELD CONFERENCE, AUGUST 11–14

As announced in the April *Bulletin*, the Wyoming Geological Association will hold its third annual summer field conference in the Wind River Basin, Wyoming, August 11 to

14. All interested geologists are invited to attend. Those wishing to take part should communicate immediately with F. HOWARD BRADY, Box 279, Casper, Wyoming. Registration is to be limited to 175 participants.

---

GEORGE S. BUCHANAN of the Gulf Coast Division of the Sohio Petroleum Company recently visited the University of Michigan, his alma mater, and gave, on March 25–27, three University lectures to the members of the department of geology. Buchanan's titles were "The Ancestral Gulf of Mexico," "Typical Gulf Coast Salt Domes and Notes on Their Discovery," and "Our Petroleum Reserves and Trends toward Synthesis."

C. B. SCHWARTZ, of the Carter Oil Company, Shreveport, Louisiana, has resigned to become vice-president of the Cook Drilling Company, Fort Worth, Texas.

CARL T. ANDERSON, recently with the Republic Natural Gas Company, Oklahoma City, has moved to Wichita Falls, Texas, as an independent operator. His address is 726 Wichita National Bank Building.

W. E. MCMURTRY has resigned from the Magnolia Petroleum Company. He is employed by the Phillips Petroleum Company at Shawnee, Oklahoma.

JAMES L. MARTIN, JR., of the Sinclair Prairie Oil Company, has been elected vice-president of the Southeastern Geological Society, Tallahassee, Florida, succeeding E. H. RAINWATER, resigned.

The Honolulu Oil Corporation has recently converted its Los Angeles Office, located in the Petroleum Building at 714 West Olympic Boulevard, Los Angeles, into a geological and land acquisition office. W. L. MATJASIC, who was formerly in the company's Bakersfield office, is now in charge of the Los Angeles office.

ALICE QUESENBERY has resigned from the Cities Service Oil Company, Wichita, Kansas, and has organized the Denver Sample Log Service, in partnership with JOE E. GUYER as business manager, Denham Building, Denver, Colorado. This service will cover wildcat wells in Colorado, Utah, and northern New Mexico. There is also a sample cut service in conjunction with the log service.

GEORGE S. BUCHANAN, formerly assistant manager of land and exploration for the Sohio Petroleum Company, has been made assistant vice-president and manager of land and exploration, with headquarters in Cleveland, Ohio.

U. R. LAVES, formerly consulting geologist in Tulsa, is now with Hubert E. Bale and Company, geologists and engineers, 518 Apco Tower, Oklahoma City, Oklahoma.

GEORGE H. ROTH, geologist for 13 years for the Shell Oil Company, Inc., and most recently senior geologist in the Bakersfield office, resigned on May 1 to join the staff of WM. ROSS CABEEN, consulting petroleum engineer and geologist, North Hollywood, California.

The Abilene Geological Society sponsored a field trip to Lower Permian and Upper Pennsylvanian type localities of the Brazos and Colorado River sections in west-central Texas, June 10–12.

RAY P. WALTERS is with the Standard Oil Company of Egypt, S. A., Box 607, Cairo, Egypt.

Production and reserve maps for South Louisiana revised through January 1, 1948, and prepared by the South Louisiana Geological Society are now available. They show accumulated production, estimated future reserves, daily average production, number of producing wells, and producing formations in all South Louisiana fields. These maps can be ordered at $2.50 per copy. Address P. F. Haberstick, Atlantic Refining Company, Box, 895, Lake Charles, Louisiana.

---

TULSA GEOLOGICAL SOCIETY STUDENT AWARD

FOREST BOVAIRD REES, senior student at the University of Tulsa, received the Tulsa Geological Society student award at the annual meeting, May 17. This award is presented to the outstanding student in the Department of Geology of Tulsa University in recognition of his achievement as a student and as a token of encouragement in his career as a geologist. The recipient is chosen by the student award committee, consisting of JAMES H. GARDNER, JOHN L. FERGUSON, and L. MURRAY NEUMANN, with the advice and collaboration of the faculty of the Department of Geology. The award consisted of a suitably inscribed bound volume of the *Bulletin* of the American Association of Petroleum Geologists for the year 1947 and a receipt for 2 years pre-paid dues as an associate member of that organization.

---

A new exploration company, the Wichita Exploration Company, which will use the latest geophysical equipment available for seismic work has been organized in Wichita Falls, Texas, by CHARLES A. BREITUNG, A. B. MCCOLLUM, and J. R. MAXEY.

At the regular annual meeting of the South Texas Section of the A.A.P.G., San Antonio, April 19, the following officers were elected: president, MARION J. MOORE, Sunray Oil Corporation; vice-president, PAUL B. HINYARD, Shell Oil Company; secretary-treasurer, MAURICE E. FORNEY, Atlantic Refining Company; member of the executive committee, LELAND L. PALMER, W. C. McBride, Inc.

The East Texas Geological Society, Tyler, Texas, elected the following officers on April 19: president, L. F. LEES, Phillips Petroleum Company; vice-president, P. S. SCHOENECK, Atlantic Refining Company; secretary-treasurer, J. C. PRICE, Magnolia Petroleum Company; and member of the executive committee, R. M. TROWBRIDGE, Trowbridge Sample Service.

W. J. LANG has recently been transferred to the Stanolind Oil and Gas Company division geological office at Fort Worth, Texas.

The American Commission on Stratigraphic Nomenclature, RAYMOND C. MOORE, chairman, has arranged for free distribution of separates of its Notes 2–6, as published in the A.A.P.G. *Bulletin*, Vol. 32, No. 3 (March, 1948), from the headquarters of the Geological Society of America, 419 West 117th Street, New York 27, New York. Notes 1 and 2 likewise may be obtained on request.

Officers of the New Mexico Geological Society are: president, ROBERT E. MURPHY, Magnolia Petroleum Company, Albuquerque; first vice-president, RICHARD MURRAY, United States Geological Survey, Ground Water Division; second vice-president, J. P. SMITH, United States Potash Company, Carlsbad; secretary-treasurer, GEORGES VORBE, New Mexico School of Mines, Socorro. Speakers at the annual March meeting at Albuquerque were: A. I. LEVORSEN, "Time of Oil Accumulation"; HARRY W. OBORNE, "Oil Exploration in San Juan Basin"; J. P. SMITH, "Potash Deposits of Germany, Alsace, and Spain"; and R. P. FISCHER, "Vanadium Deposits of Colorado Plateau."

The Dallas Geophysical Society recently elected new officers: president, W. W. NEWTON, Geotechnical Corporation; first vice-president, K. E. BURG, Geophysical Service, Inc.; second vice-president, D. RAY DOBYNS, Magnolia Petroleum Company; secretary-treasurer, W. G. SMILEY, Sun Oil Company.

HAROLD N. FISK, of the School of Geology at Louisiana State University, is in the employ of the Humble Oil and Refining Company, Houston, Texas.

J. L. MCADAMS, formerly employed by the Bishop Oil Company, is with the Bay Petroleum Corporation, Wichita Falls, Texas.

JAMES D. VINE has left Harvard University to be employed in the Fuels Section of the United States Geological Survey in central Montana.

JOHN H. DANTE is in the employ of J. J. Lynn, operating in Illinois. His address is Box 281, Flora, Illinois.

ROBERT B. MCCONNELL has left the employ of the Venezuelan Atlantic Refining Company, to be employed as an engineer by the Baroid Sales Division of the National Lead Company, in Powell, Wyoming.

F. G. FOX has completed the requirements for the Ph.D. degree in the University of Oklahoma, and has rejoined the staff of Imperial Oil Ltd., his former employer. He expects to carry on stratigraphic studies in the Alberta foothills. His address is Imperial Oil Ltd., 339–7th Avenue West, Calgary, Alberta, Canada.

W. H. TWENHOFEL, of University of Wisconsin, lectured on "Marine Cycle on Submerged and Submerging Coasts" before the Oklahoma City Geological Society at the evening meeting, April 19.

EARLE F. TAYLOR, of DeGolyer and MacNaughton, Dallas, Texas, talked on "Petroleum Geology and Development in Brazil," before the Houston Geological Society, May 24.

HUGH D. MISER, formerly chief of Fuels Division of the United States Geological Survey, presented a paper before the Oklahoma City Geological Society on May 18, entitled "Some Notes on Geology and Geologists 1907–1947."

J. CHAPMAN BROWN, consulting geologist of the West African Gold Corporation, Ltd., Tarkwa, Gold Coast Colony, died of heart failure on March 27, at the age of 54 years. He was engaged in geological examination of a mining property at Que Que, South Rhodesia, at the time of his death.

ROBERT H. PALMER, engaged in consulting practice in Cuba during the past 20 years, died at Bay Pines, Florida, on May 14, at the age of 65 years.

LLOYD WILLIAM STEPHENSON, of the United States Geological Survey, Washington, D. C., was awarded a Department of the Interior gold medal for distinguished contributions to the science of geology, especially for his studies and intimate knowledge of the Coastal Plain. The presentation was made by Secretary of the Interior J. A. Krug on April 28. Stephenson has been in U.S.G.S. service more than 38 years.

FRANK S. HUDSON is consulting geologist of the Capital Company, oil-producing subsidiary of the Transamerica Corporation. His business address is Capital Company, 1 Powell Street, San Francisco.

RENE POMEYROL, formerly with the Bureau de Recherches de Pétrole of the French

Government in New Caledonia, is now employed as senior geologist by the Texas Petroleum Company, Apartado 267, Caracas, Venezuela. He is stationed in Maracaibo.

Two additions to the geology faculty at the University of Kansas have been announced: H. A. IRELAND, now director of geologic research for the Standard Oil Company of Texas, will become professor of geology; and A. G. FISCHER, now on the staff of the University of Rochester, New York, will become an instructor. Both appointments are effective in September.

RAYMOND C. MOORE, professor of geology and research director of the State Geological Survey at the University of Kansas, will attend the International Geological Congress in London, England, in August. He will be official representative of the University, the Geological Society of America, the Paleontological Society, the Society of Economic Paleontologists and Mineralogists and the Association of American State Geologists. Moore has been State geologist and on the University of Kansas faculty since 1916.

---

SEVENTH PACIFIC SCIENCE CONGRESS, NEW ZEALAND, FEBRUARY, 1949

The 7th Pacific Science Congress is to be held in New Zealand in February, 1949. The Congress will be organized in ten divisions; within Divisions there will be a varying number of Sections. The program is arranged in the form of Symposia for the discussion of topics of wider interest; within Divisions subjects of specialist or technical interest will be presented at Section meetings. The Division of Geophysics and Geology is outlined as follows.

I. DIVISION OF GEOPHYSICS AND GEOLOGY
SYMPOSIA
(i) Structure of Pacific Basin (3 sessions)
(a) Mountain Structure (Including report of Standing Committee on Mountain Structure, H. A. Brouwer)
(b) Volcanology (Including relevant parts of report of Standing Committee on Volcanology, P. Marshall)
(c) Seismology (Including relevant parts of report of Standing Committee on Seismology, Ernest A. Hodgson)
(ii) Research Program on Earth Sciences for Pacific Basin
SECTIONAL DISCUSSIONS
(i) Naturally Occurring Thermal Waters in Pacific Region and Their Utilization
(ii) Seismology, including (a) earthquake seismology
(b) seismo-meteorology
(c) seismology and engineering
(iii) Problem of Eustatism in Pacific Region
(iv) Geological History of Pacific Basin
(v) Problems of Geophysics in Pacific Area (other than those relating to structure)
(vi) Mineral Resources and Power Resources of Pacific Area

Further information may be obtained from HAROLD J. COOLIDGE, executive secretary, Pacific Science Board, National Research Council, 2101 Constitution Avenue, Washington 25, D. C., or from GILBERT ARCHEY, Secretary-General, Seventh Pacific Science Congress, Auckland Institute and Museum, Box 27, Newmarket, Auckland, S.E. 1, New Zealand.

---

The Geological Forum of the Pacific Section of the Association presented the following program at Los Angeles on May 17: "Geology of the Ruhr Saar Coal Fields with Reference to Mining Conditions During the European Campaign," by LOUIS MCCABE, director of Air Pollution Control District; "Distribution of Sediments on the East Asiatic Continental Shelf," by KENNETH EMERY, University of Southern California; and "Western Mountain Scenery, Including the Canadian Rockies," by PAUL LOVE, photographer.

BAXTER BOYD, zone geologist of the Continental Oil Company, Fort Worth, Texas, presented an illustrated paper on "The Butterfly Oil Field, Oklahoma," at the luncheon meeting of the Tulsa Geological Society, May 28.

CARL A. MOORE, of the University of Oklahoma, spoke on "The Morrow Formation of Northeastern Oklahoma" at the regular meeting of the Tulsa Geological Society, at the University of Tulsa, May 17.

New officers of the Tulsa Geological Society are: president, JERRY E. UPP, Amerada Petroleum Corporation; first vice-president, W. REESE DILLARD, consultant; second vice-president, THOMAS E. MATSON, Pure Oil Company; secretary, NOEL EVANS, consultant; editor, JOHN C. MAHER, United States Geological Survey, Federal Building. Members of the executive committee are: CHARLES G. CARLSON, J. B. LEISER, RUSSELL TARR, and E. O. MARKHAM.

E. G. WOODRUFF, of Tulsa, Oklahoma, has been elected an honorary member of the Tulsa Geological Society. The society was organized in 1920 and Woodruff was its first president.

JARVIS GARST, district geologist for the Union Oil Company of California at Jackson, Mississippi, for the past 4 years, is employed as geologist in the Jackson office of the Honolulu Oil Company.

DAVID HAWLEY has left Columbia University, New York, to go to the department of geology, Mount Holyoke College, South Hadley, Massachusetts.

WALTER W. BUTCHER has resigned from the Creole Petroleum Corporation, Caracas, Venezuela, where he was assistant head subsurface geologist. He is independently engaged at Norman, Oklahoma, Box 796.

EGIDIO FERUGLIO has left the Instituto del Petroleo de la Universidad Nacional, in Mendoja, Argentina, and has returned to Italy. His address is Feletto Umberto (Prov. Udine).

ROBERT L. BENISH has changed his connections from the Atlantic Refining Company to the Lloyd H. Smith Exploration Company, City National Bank Building, Houston, Texas.

J. R. SPARENBERG, formerly with the Houston Natural Gas Corporation, is geologist and manager of the Houston office of the Texas Eastern Transmission Corporation, City National Bank Building, Houston.

F. A. GRASER, recently associate professor of petroleum engineering at the University of Missouri School of Mines and Metallurgy, Rolla, is in the employ of the Cleveland Oil Company, Subway Terminal Building, Los Angeles, California.

---

### HOUSTON GEOLOGICAL SOCIETY STUDENT AWARDS

At the Houston Geological Society's annual Texas A. & M. Student Awards meeting, held on May 13, two students were honored: JOHN HONEA, Houston, Texas, student geologist, who won with his paper "The Effects of Sedimentation on the Marine Organisms of the Gulf Coast of Texas"; and HAROLD G. VAN HORN, Homer, Louisiana, student petroleum engineer, who won with his paper "Gas Hydrates." The presentation was made by CHARLES H. SAMPLE, president of the Houston Geological Society, and PAUL WEAVER, president of the American Association of Petroleum Geologists.

Houston Geological Society, Texas A. & M. College Student Awards. *Left to right:* John Honea, Houston, Texas; Harold G. Van Horn, Homer, Louisiana; Charles Sample, president, Houston Geological Society; Paul Weaver, president, American Association of Petroleum Geologists.

Five Houston oil-company executives served as the judges: HAROLD DECKER, Pan American Production Company; ROY R. MORSE, Shell Oil Company, Inc.; GEORGE SAWTELLE, Kirby Petroleum Company; MORGAN DAVIS, Humble Oil and Refining Company; and E. R. FILLEY, The Texas Company. MICHEL T. HALBOUTY, consulting geologist, was chairman of the awards committee.

Winners of the awards are presented with associate membership in the A.A.P.G. by the Houston Geological Society. The purpose of the student awards can not be better expressed than in an article by W. A. VER WIEBE, in the *Bulletin*, Vol. 24, No. 11 (November, 1940), page 2019.

> The idea of offering certain outstanding students a definite incentive for extra interest in the subject of petroleum geology was put into concrete form at a meeting of the West Texas Geological Society on June 21, 1939 . . . .
>
> The second society affiliated with the A.A.P.G. which adopted the Student Award Plan was the Houston Geological Society. At a meeting held on May 2, 1940, a plan was adopted to honor students in the department of geology and petroleum engineering at the Texas Agricultural and Mechanical Arts College . . . .

---

FAWZI ISKANDER, the senior geologist of the Standard Oil Company of Egypt, has been appointed as core hole and East Coast of Gulf of Suez district geologist; he has also been delegated by Fouad First University to give a course of lectures on petroleum field geology to the senior class of the Faculty of Science, Cairo.

ENRIQUE CAMACHO, formerly with the Atlantic Refining Company of Cuba, is with the Shell Oil Company, Inc., Lake Charles, Louisiana.

O. A. SEAGER is with the Arabian-American Oil Company, Dhahran, Saudi-Arabia.

The new officers to the Oklahoma City Geological Society, elected May 29, are as follows: president, ROBERT R. WHEELER, consultant, 1216 Petroleum Building; vice-president, L. R. WILSON, Carter Oil Company; treasurer, ELWYN R. OWEN, Phillips Petroleum Company; secretary, JOHN JANOVY, Tide Water Associated Oil Company, 918 Hales Building.

K. ARBENZ, of the University of Oklahoma, addressed the Oklahoma City Geological Society, May 13, 1948, on "The Geology of Switzerland."

The following officers for 1948–1949 were elected by the Mississippi Geological Society at the final meeting of the 1947–1948 season at Jackson, on May 28, 1948: president, ROBERT D. SPRAGUE, Sinclair-Wyoming Oil Company; vice-president, CARL F. GRUBB, Superior Oil Company; secretary-treasurer, E. T. MONSOUR, consultant, Box 2571, West Jackson, Mississippi.

LOUIS S. Wallace has resigned as geologist for the Superior Oil Company of California and has accepted a position with Signal Oil and Gas Company as division geologist at Fort Worth. He is temporarily stationed at Oklahoma City with offices at 1216 Petroleum Building, pending his transfer to Fort Worth.

DAVID DONOGHUE, consulting geologist of Fort Worth, Texas, has been in Colombia, South America, studying the crude oil reserves.

WILLIAM ROY HOGAN, JR., has left the Erle P. Halliburton Company, Duncan, Oklahoma, to join the Neeld and Hood Drilling Company, Wichita Falls, Texas.

ROGER H. COWIE, formerly of the geology department of the Missouri School of Mines, Rolla, is in the employ of the Shell Oil Company, Inc., Lake Charles, Louisiana.

ORLO E. CHILDS, of Colgate University, Hamilton, New York, has accepted appointment as assistant professor of geology at the University of Wyoming, Laramie.

JIM B. MCWILLIAMS, of Norman, Oklahoma, is with the Cities Service Oil Company, Oil Hill, Kansas.

DONALD M. MURPHREE, of Norman, Oklahoma, is with the British-American Oil Producing Company, Casper, Wyoming.

MORGAN J. DAVIS, chief geologist and manager of exploration of the Humble Oil and Refining Company, Houston, Texas, has been elected to the board of directors of the company.

A. W. AMBROSE of Bartlesville, Okalhoma, president of Cities Service Oil Co. (Del.), has announced that ROBERT L. KIDD had been elected a vice-president of the company.

The Geological Forum of the Pacific Section of the Association presented the following program, at Los Angeles, June 21: "Geology of the South Flank of the Uinta Mountains near Vernal, Utah," by DOUGLAS M. KINNEY, United States Geological Survey; "Oil and Gas Fields of Montana," by ARTHUR S. HUEY, Hancock Oil Company; "Electronics in the Oil Industry, Including a Discussion of the Magna-Tector and Surface Recorder," by LLOYD A. CALHOUN, McCullough Gun Perforators.

The following officers were elected at the June 14 meeting of the Houston Geological Society in Houston, Texas, for the 1948–1949 term: president, A. F. CHILDERS, JR., Gulf Oil Corporation; vice-president, HERSHAL C. FERGUSON, consultant; secretary, R. R. RIEKE, Schlumberger Well Surveying Corporation; treasurer, MARY L. HOLLAND, Stanolind Oil and Gas Company.

PARKER D. TRASK has been appointed supervising geologist for the California State Division of San Francisco Bay Toll Crossings to help with geological and oceanographical engineering problems connected with the building of new crossings over San Francisco Bay. Trask states that plans for the new symposium on practical applications of sedimentation that is being sponsored by a Committee for a Symposium on Sedimentation of the Division of Geology and Geography of the National Research Council are progressing very satisfactorily. Trask is chairman of this committee. About 40 specialists in different fields of engineering and geology are writing papers on the use of sedimentation in the practical problems on which they work. The object of the symposium is to point out to the engineer and to the geologist the many different ways in which knowledge of sedimentation can help the solution of practical problems. The volume is scheduled for completion in about a year.

ROBERT W. CLARK, chief geologist of the Western Gulf Oil Company, Los Angeles, California, died on June 5. He was vice-president of the Association in 1943.

CHARLES H. NEFF is in the employ of the Gulf Oil Corporation, 17 Battery Place, New York.

President PAUL WEAVER has visited local groups of Association members recently in Tulsa, Shreveport, Tyler, Dallas, Houston, and New Orleans. On June 14 he discussed "Field Trips in General" at the meeting of the Houston Geological Society, and JOHN L. FERGUSON, of the Amerada Petroleum Corporation, Tulsa, Oklahoma, showed a technicolor moving picture of the Ouachita Mountain field trip of the Tulsa Geological Society of last May.

PAUL F. OSBORNE, consulting geologist of Dallas, Texas, has changed his address to Caixa Postal 470, Salvador, Bahia, Brazil.

E. E. REHN, of the Sohio Petroleum Company, eastern division, land and geological departments, is now situated at Seventh and Locust Streets, Evansville, Indiana.

L. E. J. BROUWER is with the Bataafsche Petroleum Maatschappy, 30 Carel van Bylandt Laan, The Hague, Holland.

GARRETT A. MUILENBURG, many years professor at the Missouri School of Mines, Rolla, has been transferred to the University of Missouri at Columbia, Missouri. He has been with the School of Mines 32 years.

E. B. RICH has resigned his position as geologist with the Chicago Corporation in Corpus Christi, Texas, and is now employed as chief geologist with Baldridge and King, Incorporated, located in McAllen, Texas.

LARRY S. MELZER, assistant district geologist at Tyler, Texas, for the Stanolind Oil and Gas Company, has been promoted and trasnferred to Midland, Texas, where he will assume duties as area geologist.

FRANK F. GROUT, professor of geology and mineralogy at the University of Minnesota, was retired on July 1. As a retirement gift, his students, colleagues, and friends pre-

sented him with a cash purse to defray his expenses to the International Geological Congress in London this summer.

The East Texas Geological Society, Tyler, Texas, in meeting of June 7, elected the following officers for the year 1948–1949, an election necessitated by the transfer and resignation of L. F. LEES, who was elected to serve as president for the coming year on April 19, but was transferred by his company to Jackson, Mississippi: president, P. S. SCHOENECK, Atlantic Refining Company; vice-president, J. C. PRICE, Magnolia Petroleum Company; secretary-treasurer, G. C. CLARK, Stanolind Oil and Gas Company. The executive committee is composed of the foregoing and R. M. TROWBRIDGE, Trowbridge Sample Service, and T. H. SHELBY, Humble Oil and Refining Company.

New officers of the Illinois Geological Society are: president, C. E. BREHM, of C. E. Brehm Drilling and Producing, Box 368, Mt. Vernon; vice-president, JOSEPH NEELY, Magnolia Petroleum Company, Mt. Vernon; secretary-treasurer, HALBERT H. BYBEE, Carter Oil Company, Box 568, Mattoon, Illinois.

STUART K. CLARK, of the Continental Oil Company, Ponca City, Oklahoma, discussed "Faulting in the Eastern Interior Basin," at the meeting of the Illinois Geological Society, June 4.

RAE PREECE, former field manager, drilling and producing department, of the Hancock Oil Company of California, has left the home office at Long Beach to become manager of the company's new Mid-Continent division, 405 Alamo National Building, San Antonio, Texas.

J. W. KISLING discussed the "Regional Geology and General Geography of Eastern Ethiopia," illustrated by moving pictures, at the final spring meeting of the Shreveport Geological Society, June 7.

ALVIN M. JACKSON has resigned his position as chief development geologist with the Arkansas Natural Companies after 13 years of service, to become associated with Lyons and Prentiss, as geologist at Shreveport, Louisiana.

C. E. BURBRIDGE, JR., formerly Mexico City manager for Cía. Minera de Peñoles, S. A., is now assistant general manager of Cía. Minera y Refinadora Mexicana, S. A., with general offices at Estación Wadley, S.L.P., Mexico.

ERIC RUDD was recently made chief geologist of the Broken Hill Prop. Company, Ltd., Melbourne, Australia.

LESLIE M. CLARK, formerly chief geologist in Western Canada for the Shell Oil Company of Canada, Limited, has resigned to become chief geologist of Canadian operations of the Barnsdall Oil Company, with headquarters at Calgary.

EDWIN L. PORCH, JR., consulting geologist of San Antonio, Texas, died last month in San Antonio at the age of 58 years.

THOMAS H. GREEN has resigned from the Shell Oil Company, Inc., to join the Sunray Oil Corporation at Oklahoma City, Oklahoma.

DAVID R. TOLAND has been transferred from the Carter Oil Company to the Creole Petroleum Corporation, Caracas, Venezuela.

JOHN R. COOMBS is a petroleum engineer in the employ of the Aetna Oil Company, Evansville, Indiana. He was recently with the Magnolia Petroleum Company in Dallas, Texas.

# PROFESSIONAL DIRECTORY

## CALIFORNIA

EVERETT C. EDWARDS
*Geologist*
501 South Coast Boulevard
Telephone 1332 Laguna Beach, California

PAUL P. GOUDKOFF
*Geologist*
Geologic Correlation by Foraminifera and Mineral Grains
799 Subway Terminal Building
LOS ANGELES, CALIFORNIA

HAROLD W. HOOTS
*Geologist*
555 South Flower
LOS ANGELES 13 CALIFORNIA

LUIS E. KEMNITZER
KEMNITZER, RICHARDS AND DIEPENBROCK
*Geologists and Petroleum Engineers*
1003 Financial Center Building
704 South Spring Street
LOS ANGELES 14, CALIFORNIA

VERNON L. KING
*Petroleum Geologist and Engineer*
707 South Hill Street
LOS ANGELES, CALIFORNIA
Vandike 7087

A. I. LEVORSEN
*Petroleum Geologist*
STANFORD UNIVERSITY CALIFORNIA

ERNEST K. PARKS
*Consultant in*
*Petroleum and Natural Gas Development and*
*Engineering Management*
614 S. Hope St.
LOS ANGELES, CALIFORNIA

HENRY SALVATORI
Western Geophysical Company
711 Edison Building
601 West Fifth Street
LOS ANGELES, CALIFORNIA

RICHARD L. TRIPLETT
*Core Drilling Contractor*
*PArkway 9925* 1660 Virginia Road
LOS ANGELES 6, CALIF.

## COLORADO

C. A. HEILAND
*Heiland Research Corporation*
130 East Fifth Avenue
DENVER 9, COLORADO

HARRY W. OBORNE
*Geologist*
620 East Fontanero Street
Colorado Springs, Colorado
Main 4711

EVERETT S. SHAW
*Geologist and Engineer*
3141 Zenobia Street
DENVER 12 COLORADO

V. ZAY SMITH L. BRUNDALL
R. McMILLAN A. R. WASEM
Geophoto Services
*Photogeologists and Consulting Geologists*
305 E & C Building DENVER 2, COLO.

## ILLINOIS

C. E. BREHM
*Consulting Geologist*
*and Geophysicist*
New Stumpp Building, Mt. Vernon, Illinois

J. L. McMANAMY
*Consulting Geologist*
Mt. Vernon, Illinois

L. A. MYLIUS
*Geologist* *Engineer*
122A North Locust Street
Box 264, Centralia, Illinois

T. E. WALL
*Geologist*
Mt. Vernon Illinois

## INDIANA

HARRY H. NOWLAN
*Consulting Geologist and Engineer*
*Specializing in Valuations*
Evansville 19, Indiana
317 Court Bldg. Phone 2-7818

## KANSAS

WENDELL S. JOHNS
PETROLEUM
GEOLOGIST
Office Phone 3-1540 600 Bitting Building
Res. Phone 2-7266 Wichita 2, Kansas

EDWARD A. KOESTER
*Petroleum Geologist*
302 Orpheum Bldg., Wichita, Kansas

## LOUISIANA

GORDON ATWATER
*Consulting Geologist*
Whitney Building
New Orleans Louisiana

WILLIAM M. BARRET, INC.
*Consulting Geophysicists*
Specializing in Magnetic Surveys
Giddens-Lane Building SHREVEPORT, LA.

## LOUISIANA

G. FREDERICK SHEPHERD
*Consulting Geologist*
123 Maryland Drive
Phone AUdubon 1403 New Orleans 18, La.

## MEXICO

C. E. BURBRIDGE, JR.
Petroleum Mining
Estación Wadley, S.L.P., Mexico
Phone: Mexican No. 1—Telegraph: Estación Wadley, via Estación Catorce, S.L.P.

## MISSISSIPPI

R. Merrill Harris Willard M. Payne
HARRIS & PAYNE
*Geologists*
100 East Pearl Bldg. Phone 4-6286
Jackson, Miss. or L. D. 89

FREDERICK F. MELLEN
*Consulting Geologist*
P.O. Box 2584
West Jackson Station
Jackson, Mississippi
113½ W. Capitol Street Phone 54541

## MISSISSIPPI

**E. T. MONSOUR**
*Consulting Geologist*
P.O. Box 2571
West Jackson Station
Jackson, Mississippi
112½ E. Capitol St. Phone 2-1368

## MONTANA

**HERBERT D. HADLEY**
*Petroleum Geologist*
Billings, Montana
801 Grand Ave. Phone 2950

## NEW MEXICO

**VILAS P. SHELDON**
*Consulting Geologist and Reservoir Performance Specialist*
Geological Reports, Valuations, Appraisals, Microscopic well cutting examination, well completion supervision, reservoir performance analyses
Office Phone 720-W Carper Building
Home Phone 702-J Artesia, New Mexico

**SHERMAN A. WENGERD**
*Petroleum Geologist*
University Station
Albuquerque Telephone 8861
New Mexico Ext. 31

## NEW YORK

**BROKAW, DIXON & McKEE**
*Geologists* *Engineers*
OIL—NATURAL GAS
Examinations, Reports, Appraisals
Estimates of Reserves
120 Broadway Gulf Building
New York Houston

**FRANK RIEBER**
*Geophysicist*
Specializing in the development of new instruments and procedures
127 East 73d St. New York 21

**BASIL B. ZAVOICO**
*Petroleum Geologist and Engineer*
220 E. 42nd St. City National Bank Bldg.
New York 17, N.Y. Houston, Texas
MUrray Hill 7-7591 Charter 4-6923

## NORTH CAROLINA

**RODERICK A. STAMEY**
*Petroleum Geologist*
109 East Gordon Street
KINGSTON NORTH CAROLINA

## OHIO

**JOHN L. RICH**
*Geologist*
General Petroleum Geology
Geological Interpretation of Aerial Photographs
University of Cincinnati
Cincinnati, Ohio

**GORDON RITTENHOUSE**
*Geologist*
*Specializing in sedimentation and Sedimentary petrology*
University of Cincinnati
Cincinnati 21, Ohio

## OKLAHOMA

**ELFRED BECK**
*Geologist*
821 Wright Box 55
TULSA, OKLA. DALLAS, TEX.

**GARTH W. CAYLOR**
*Consulting Geologist*
206 Elm Oil Building
624 South Cheyenne Avenue
Tel. 2-1783 Tulsa, Oklahoma

**CRAIG FERRIS**
*Geophysicist*
E. V. McCollum & Co.
515 Thompson Bldg.
Tulsa 3, Okla.

## OKLAHOMA

E. J. HANDLEY
*Vice-President*
CENTURY GEOPHYSICAL CORPORATION
Phone 5-1171
1333 North Utica Tulsa 6, Okla.

R. W. LAUGHLIN
WELL ELEVATIONS
LAUGHLIN-SIMMONS & CO.
615 Oklahoma Building
TULSA OKLAHOMA

CLARK MILLISON
*Petroleum Geologist*
Philtower Building
TULSA OKLAHOMA

HUGH C. SCHAEFFER
*Geologist and Geophysicist*
Schaeffer Geophysical Company
National Bank of Tulsa Building
TULSA, OKLAHOMA

WARE & KAPNER
SAMPLE LOG SERVICE
*Wildcat Sample Log Service*
*Covering Southern Oklahoma*
John M. Ware H. H. Kapner
Tulsa, Oklahoma
332 East 29th Place 4-2539

ROBERT R. WHEELER
*Consulting Geologist*
Tekton Oil Co., Inc.
Specializing in Anadarko Basin
Possibilities and Prospects
Phone 7-1142
12th Floor, Petroleum Bldg. Oklahoma City

WALTER E. HOPPER
*Geologist and Consultant*
Petroleum and Natural Gas
Reports Appraisals
Estimates of Reserves
510 National Mutual Building Tulsa 3, Oklahoma

FRANK A. MELTON
*Consulting Geologist*
*Aerial Photographs*
*and Their Structural Interpretation*
1010 Chautauqua Norman, Oklahoma

P. B. NICHOLS H. T. BROWN
*Mechanical Well Logging*
THE GEOLOGRAPH COMPANY, INC.
27 N.E. 27
Phone 58-5511 P.O. Box 1291
Oklahoma City 1, Oklahoma

JOSEPH A. SHARPE
*Geophysicist*
FROST GEOPHYSICAL CORPORATION
4408 South Peoria Ave. Tulsa 3, Okla.

G. H. WESTBY
*Geologist and Geophysicist*
*Seismograph Service Corporation*
Kennedy Building Tulsa, Oklahoma

## PENNSYLVANIA

HUNTLEY & HUNTLEY
*Petroleum Geologists*
*and Engineers*
Grant Building, Pittsburgh, Pa.
L. G. HUNTLEY
J. R. WYLIE, JR.
JAMES F. SWAIN

## TEXAS

JOSEPH L. ADLER
*Geologist and Geophysicist*
*Contracting Geophysical Surveys*
*in Latin America*
Independent Exploration Company
Esperson Building Houston, Texas

CHESTER F. BARNES
*Geologist and Geophysicist*
Petroleum Bldg. P.O. Box 266, Big Spring, Tex.

## TEXAS

BRYAN D. BECK, JR.
*Petroleum Consultant*
Geology Engineering Micropaleontology
Drilling Blocks—Farmouts
Well Promotions—Production
222 Orleans Street Beaumont, Texas

JOHN L. BIBLE
*Consulting Geophysicist*
TIDELANDS EXPLORATION COMPANY
Gravity Surveys on Land and Water
2626 Westheimer
Houston 6, Texas

HART BROWN
BROWN GEOPHYSICAL COMPANY
*Gravity*
P.O. Box 6005 Houston 6, Texas

R. W. BYRAM
R. W. BYRAM & COMPANY
*Geologists and Petroleum Engineers*
Texas Oil and Gas Statistics Austin, Texas

D'ARCY M. CASHIN
*Geologist* *Engineer*
*Specialist Gulf Coast Salt Domes*
Examinations, Reports, Appraisals
Estimates of Reserves
705 Nat'l Standard Bldg.
HOUSTON, TEXAS

CUMMINS, BERGER & PISHNY
*Consulting Engineers & Geologists*
Specializing in Valuations
1603 Commercial Standard Bldg.
Fort Worth 2, Texas
Ralph H. Cummins
Walter R. Berger
Chas. H. Pishny

E. DEGOLYER
*Geologist*
Esperson Building
Houston, Texas
Continental Building
Dallas, Texas

R. L. BECKELHYMER
*Consulting Geologist*
Domestic and Foreign Experience
307 Rusk Building Houston 2, Texas

IRA A. BRINKERHOFF
*Geologist*
Associated with
CUMMINS, BERGER & PISHNY
National Standard Building
Houston, Texas

E. O. BUCK
*Geologist and Petroleum Engineer*
NATIONAL BANK OF COMMERCE
GULF BUILDING, HOUSTON, TEXAS

GEORGE W. CARR
Carr Geophysical Company
Commerce Building Houston, Texas

PAUL CHARRIN
*Geologist and Geophysicist*
UNIVERSAL EXPLORATION COMPANY
2044 Richmond Road, Houston 6, Texas
913 Union National Bank Building
Houston 2, Texas

R. H. DANA
*Southern Geophysical Company*
Sinclair Building
FORT WORTH, TEXAS

ALEXANDER DEUSSEN
*Consulting Geologist*
Specialist, Gulf Coast Salt Domes
1006 Shell Building
HOUSTON, TEXAS

## TEXAS

DAVID DONOGHUE
*Consulting Geologist*
*Appraisals - Evidence - Statistics*
Fort Worth National Bank Building — FORT WORTH, TEXAS

RALPH H. FASH
*Consulting Chemist*
Chemistry applied to the search for oil
1811 W. T. Waggoner Bldg.
Fort Worth 2, Texas
Telephones: Office 3-7351 Res. 5-3852

JOHN A. GILLIN
*National Geophysical Company*
Tower Petroleum Building
Dallas, Texas

CECIL HAGEN
*Geologist*
Gulf Bldg. — HOUSTON, TEXAS

GEO. P. HARDISON
*Petroleum Geologist*
426-430 Wichita National Bank Building
Wichita Falls, Texas

L. B. HERRING
*Geologist*
Natural Gas — Petroleum
Second National Bank of Houston, Houston, Texas

SAMUEL HOLLIDAY
*Consulting Paleontologist*
207 Mulberry Lane
Bellaire, Texas

F. JULIUS FOHS
*Geologist*
433 Esperson Building
Houston 2, Texas
11 E. 44th Street
New York 17, N.Y.

DONALD A. GRAY
*Consulting Geologist*
Reports—Appraisals—Brokerage
1803 Dayton — WICHITA FALLS, TEXAS
Phone 4615

MICHEL T. HALBOUTY
*Consulting Geologist and Petroleum Engineer*
Suite 729-32, Shell Bldg.
Houston 2, Texas — Phone P-6376

SIDON HARRIS
*Southern Geophysical Company*
1003 Sinclair Building, FORT WORTH 2, TEXAS

JOHN M. HILLS
*Consulting Geologist*
Midland, Texas
Box 418 — Phone 1015

R. V. HOLLINGSWORTH
HAROLD L. WILLIAMS
PALEONTOLOGICAL LABORATORY
Box 51 — Phone 2359
MIDLAND, TEXAS

## TEXAS

J. S. HUDNALL G. W. PIRTLE
HUDNALL & PIRTLE
*Petroleum Geologists*
Appraisals Reports
Peoples Nat'l Bank Bldg. TYLER, TEXAS

C. E. HYDE
*Geologist and Oil Producer*
1715 W. T. Waggoner Building
FORT WORTH 2, TEXAS

JOHN S. IVY
*Geologist*
1124 Niels Esperson Bldg., HOUSTON, TEXAS

RALPH S. JACKSON
*Consulting Geophysicist*
BEEVILLE TEXAS

W. P. JENNY
*Consulting Geologist and Geophysicist*
AERIAL MAGNETIC and MICROMAGNETIC
SURVEYS and INTERPRETATIONS
GEOPHYSICAL CORRELATIONS
1404 Esperson Bldg. HOUSTON, TEXAS

V. ROBERT KERR
*Consulting Seismologist*
Original and Review Interpretations
Associated with
CUMMINS, BERGER AND PISHNY
Commercial Standard Bldg. Fort Worth 2, Tex.

H. KLAUS
*Geologist and Geophysicist*
KLAUS EXPLORATION COMPANY
Geophysical Surveys and Interpretations
Gravitymeter, Torsion Balance
and Magnetometer
Box 1617, Lubbock, Texas

LESTER A. LUCKE
*Geologist*
900 Brook Avenue
Wichita Falls, Texas

JOHN D. MARR
*Geologist and Geophysicist*
SEISMIC EXPLORATIONS, INC.
Gulf Building Houston, Texas

PHIL F. MARTYN
*Petroleum Geologist*
2703 Gulf Building
Charter 4-0770 Houston 2, Texas

HAYDON W. McDONOLD
*Geologist and Geophysicist*
KEYSTONE EXPLORATION COMPANY
2813 Westheimer Road Houston, Texas

GEORGE D. MITCHELL, JR.
*Geologist and Geophysicist*
ADVANCED EXPLORATION COMPANY
622 First Nat'l Bank Bldg. Houston 2, Texas

R. B. MITCHELL
*Consulting Geologist*
THE R. B. MITCHELL COMPANY
City National Bank Bldg. Houston 2, Texas

P. E. NARVARTE
*Consulting Geophysicist*
Seismic Interpretations
Specializing in Faulting and Velocity Analysis
Current Supervision and Review
307 Insurance Building San Antonio, Texas

## TEXAS

LEONARD J. NEUMAN
*Geology and Geophysics*
Contractor and Counselor
Reflection and Refraction Surveys
943 Mellie Esperson Bldg. Houston, Texas

J. C. POLLARD
Robert H. Ray, Inc.
Rogers-Ray, Inc.
*Geophysical Engineering*
2911 Gulf Building Houston 2, Texas

F. F. REYNOLDS
*Geophysicist*
SEISMIC EXPLORATIONS, INC.
2911 Gulf Building Houston 2, Texas

SIDNEY SCHAFER
*Consulting Geophysicist*
Seismic Reviews Interpretations
Exploration Problems
3775 Harper St. Houston 5, Texas

A. L. SELIG
*Consulting Geologist*
Gulf Building Houston, Texas

WM. H. SPICE, JR.
*Consulting Geologist*
2101-02 Alamo National Building
SAN ANTONIO, TEXAS

W. W. WEST
PERMIAN BASIN SAMPLE LABORATORY
123 Midland Tower Phone: 3400 Midland, Texas
All current West Texas and New Mexico Permian Basin wildcat and key pool well sample descriptions on a monthly subscription basis.
Descriptions on old wells.

DABNEY E. PETTY
10 Tenth Street
SAN ANTONIO, TEXAS
No Commercial Work Undertaken

ROBERT H. RAY
ROBERT H. RAY, INC.
*Geophysical Engineering*
*Gravity Surveys and Interpretations*
National Standard Bldg. Houston 2, Texas

C. W. SANDERS
*Consulting Geologist*
2413 Colonial Parkway Fort Worth 4, Texas
Phone 4-7188

HUBERT L. SCHIFLETT
STATES EXPLORATION COMPANY
Sherman Texas

E. JOE SHIMEK HART BROWN
GEOPHYSICAL ASSOCIATES
Seismic
P.O. Box 6005 Houston 6, Texas

HARRY C. SPOOR, JR.
*Consulting Geologist*
*Petroleum . . . . . Natural Gas*
Commerce Building Houston, Texas

CHARLES C. ZIMMERMAN
*Geologist and Geophysicist*
KEYSTONE EXPLORATION COMPANY
2813 Westheimer Road Houston, Texas

WEST VIRGINIA

DAVID B. REGER
*Consulting Geologist*
217 High Street
MORGANTOWN WEST VIRGINIA

WYOMING

E. W. KRAMPERT
*Geologist*
P.O. Box 1106
CASPER, WYOMING

HENRY CARTER REA
*Consulting Geologist*
*Specialist in Photogeology*
Box 294
CASPER, WYOMING

***Source Data***

**DIRECTORY OF GEOLOGICAL MATERIAL IN NORTH AMERICA**

By

J. V. HOWELL AND A. I. LEVORSEN
Tulsa, Oklahoma, and Stanford University, California

I. General Material:—National and continental in area
- A. Publications and non-commercial publishing agencies, regional, national, and continental
- B. Bibliographies, general
- C. Dictionaries, glossaries, encyclopedias, statistics, handbooks
- D. Miscellaneous books and publications of general geological interest
- E. Commercial map publishers
- F. Regional and national geologic and physiographic maps
- G. State and Province geological maps
- H. Trade journals: oil, gas, mineral industry
- I. Libraries furnishing photostat and microfilm service
- J. Thin-section and rock-polishing service

II. Specific Material:—State and Province in area
- A. Canada, by provinces, and Newfoundland
- B. Central American countries
- C. Mexico
- D. United States—states and territories

*Originally published as Part II of the August, 1946, Bulletin*

PRICE, 75¢ POSTPAID

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
BOX 979, TULSA 1, OKLAHOMA, U.S.A.

# GEOLOGICAL AND GEOPHYSICAL SOCIETIES

## THE SOCIETY OF EXPLORATION GEOPHYSICISTS

*President* - - - - - - - - L. L. Nettleton
Gravity Meter Exploration Co.
1348 Esperson Bldg., Houston, Tex.
*Vice-President* - - - - - Andrew J. Gilmour
Amerada Petroleum Corporation
Box 2040, Tulsa, Oklahoma
*Editor* - - - - - - - - - - M. King Hubbert
Shell Oil Company, Inc.
Houston, Texas
*Secretary-Treasurer* - - - - - E. V. McCollum
E. V. McCollum and Company
515 Thompson Building, Tulsa, Oklahoma
*Past-President* - - - - - - - - Cecil H. Green
Geophysical Service, Inc.
1311 Republic Bank Building, Dallas, Texas
*Business Manager* - - - - - Colin C. Campbell
Room 210, 817 South Boulder, Tulsa, Oklahoma
P.O. Box 1614

## CALIFORNIA

### PACIFIC SECTION AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

*President* - - - - - - - William P. Winham
Standard Oil Company of California
Box 2437, Terminal Annex, Los Angeles 54
California
*Vice-President* - - - - - - - - Harvey W. Lee
Union Oil Company, 617 W. 7th St.
Los Angeles 14, California
*Secretary-Tredsurer* - - - - - P. H. Gardett
General Petroleum Corp., 108 W. 2d St.
Los Angeles 12, California

Monthly meetings. Visiting geologists are welcome.

## COLORADO

### ROCKY MOUNTAIN ASSOCIATION OF GEOLOGISTS

DENVER, COLORADO

*President* - - - - - - - - - C. E. Manion
Consulting Geologist
1740 Grape Street
*1st Vice-President* - - - - - - - L. Brundall
Geophoto Services
305 E & C Building
*2d Vice-President* - - - - - - - S. W. Lohman
U. S. Geological Survey
136 New Customhouse
*Secretary-Treasurer* - - - - Kirk C. Forcade
Frontier Refining Company
410 Boston Building

Evening dinner (6:30) and technical program (8:00) first Tuesday each month or by announcement.

## FLORIDA

### SOUTHEASTERN GEOLOGICAL SOCIETY

Box 841
TALLAHASSEE, FLORIDA

*President* - - - - - - - - Paul L. Applin
U. S. Geological Survey
*Vice-President* - - - - - James L. Martin, Jr.
Sinclair Prairie Oil Company
*Secretary-Treasurer* - - - Eleanor T. Caldwell
Humble Oil and Refining Company,
Box 506

Meetings will be announced. Visiting geologists and friends are welcome.

## ILLINOIS

### ILLINOIS GEOLOGICAL SOCIETY

*President* - - - - - - - - - - C. E. Brehm
C. E. Brehm Drilling & Producing
Mt. Vernon
*Vice-President* - - - - - - - - Joseph Neely
Magnolia Petroleum Company
Box 535, Mt. Vernon
*Secretary-Treasurer* - - - - Halbert H. Bybee
Carter Oil Company
Box 568, Mattoon

Meetings will be announced.

## INDIANA-KENTUCKY

### INDIANA-KENTUCKY GEOLOGICAL SOCIETY

EVANSVILLE, INDIANA

*President* - - - - - - - - J. Albert Brown
Sohio Petroleum Company
*Vice-President* - - - - - George E. Taylor
Continental Oil Company, 606 Division St.
*Secretary-Treasurer* - - - - - - E. J. Combs
Sun Oil Company, Box 717

Meetings will be announced.

## KANSAS

### KANSAS GEOLOGICAL SOCIETY

WICHITA, KANSAS

*President* - - - - - - - - - - L. C. Hay
Independent, 703 Union Nat'l. Bank Bldg.
*Vice-President* - - - - - - - - Don W. Payne
Sinclair Prairie Oil Company
*Secretary-Treasurer* - - - Shirley E. Lenderman
Stanolind Oil and Gas Company

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. Noon luncheons, first and third Monday of each month at Wolf's Cafeteria. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka. Visiting geologists and friends welcome.

## LOUISIANA

### NEW ORLEANS GEOLOGICAL SOCIETY

NEW ORLEANS, LOUISIANA

*President* - - - - - - - - - Joe B. Hudson
Humble Oil and Refining Company
*Vice-President and Program Chairman* - - -
- - - - - - - - - - - - - Fred S. Goerner
California Company, 1818 Canal Building
*Secretary-Treasurer* - - - - - *Ame Vennema*
Schlumberger Well Surveying Corporation

Meets the first Monday of every month October-May, inclusive, 12 noon, St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

## LOUISIANA

### THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

*President* - - - - - - - Claude N. Valerius
Barnsdall Oil Company
427 Ricou-Brewster Building
*Vice-President* - - - - Walter F. Hamilton
Gulf Refining Company
Box 1731
*Secretary-Treasurer* - - - - - - R. T. Wade
Schlumberger Well Surveying Corporation
Box 92

Meets monthly, September to May, inclusive, in the State Exhibit Building, Fair Grounds. All meetings by announcement.

### SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

*President* - - - - - - - - D. E. Newland
Magnolia Petroleum Company
*Vice-President* - - - - - - E. M. Ross, Jr.
Amerada Petroleum Corporation
*Secretary* - - - - - - - - H. L. Tipsword
Magnolia Petroleum Company, Box 872
*Treasurer* - - - - - - - - Philip R. Allin
Gulf Oil Corporation

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

## MICHIGAN

### MICHIGAN GEOLOGICAL SOCIETY

*President* - - - - - - - - Charles K. Clark
Pure Oil Company
402 2d Nat'l. Bank Bldg., Saginaw
*Vice-President* - - - - - - W. A. Kelly
Michigan State College
East Lansing
*Secretary-Treasurer* - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing
*Business Manager* - - - - - Jack Mortenson
Sohio Petroleum Company, Mt. Pleasant

Meetings: Monthly, November through May, at Michigan State College, East Lansing, Michigan. Informal dinners at 6:30 P.M., followed by discussions. Visiting geologists are welcome.

## MISSISSIPPI

### MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

*President* - - - - - - - - - R. D. Sprague
Sinclair Wyoming Oil Company
*Vice-President* - - - - - - Carl F. Grubb
Superior Oil Company
*Secretary-Treasurer* - - - - - E. T. Monsour
Consultant, Box 2571, West Jackson

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., The Creole Room, LeFleur's Restaurant, Jackson, Mississippi. Visiting geologists welcome to all meetings.

## OKLAHOMA

### ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

*President* - - - - - - Walter Neustadt, Jr.
Westheimer-Neustadt Oil Company, Box 974
*Vice-President* - - - - - Richard G. Kendall
The California Company, Box 153
*Secretary-Treasurer* - - - - - Frank Millard
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

### OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

*President* - - - - - - - - Robert R. Wheeler
Consultant, 1216 Petroleum Building
*Vice-President* - - - - - - L. R. Wilson
Carter Oil Company
1300 Apco Tower
*Secretary* - - - - - - - - - John Janovy
Tide Water Associated Oil Company,
918 Hales Building
*Treasurer* - - - - - - - - Elwyn R. Owens
Phillips Petroleum Company

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second and fourth Thursday of each month, at 12:00 noon, Y.W.C.A.

### SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

*President* - - - - - - - - - Fred J. Smith
Sinclair Prairie Oil Company
Box 991, Seminole
*Vice-President* - - - - - - Doyle M. Burke
The Texas Company
Box 1007, Shawnee
*Secretary-Treasurer* - - - - Marcelle Mousley
Atlantic Refining Company, Box 169
Shawnee

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

### TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

*President* - - - - - - - - - Jerry E. Upp
Amerada Petroleum Corporation, Box 2040
*1st Vice-President* - - - - W. Reese Dillard
Consultant, Box 2204
*2d Vice-President* - - - - Thomas E. Matson
Pure Oil Company
*Secretary-Treasurer* - - - - - - Noel Evans
Consultant, 1510 Philtower Building
*Editor* - - - - - - - - - - John C. Maher
U. S. Geological Survey
Federal Building

Meetings: First and third Mondays, each month, from October to May, inclusive, at 8:00 P.M., University of Tulsa, Student Union or Tyrrell Hall. Luncheons: Every Friday (October-May), Chamber of Commerce Building.

## PENNSYLVANIA

### PITTSBURGH GEOLOGICAL SOCIETY
PITTSBURGH, PENNSYLVANIA

*President* - - - - - - - - John T. Galey
Independent, Box 1675
*Vice-President* - - - - - - - W. B. Robinson
Gulf Research and Development Company
Box 2038
*Secretary* - - - - - - - - James C. Patton
Equitable Gas Company
610 Wood St.
*Treasurer* - - - - - - - - Sidney A. Galpin
Peoples Natural Gas Company
545 William Penn Place

Meetings held each month, except during the summer. All meetings and other activities by special announcement.

## TEXAS

### ABILENE GEOLOGICAL SOCIETY
ABILENE, TEXAS

President - - - - - - Frank B. Conselman
Consulting Geologist
*Vice-President* - - - - - - - J. R. Day
Pan American Production Company
*Secretary-Treasurer* - - - - Riley G. Maxwell
Consulting Geologist
Box 1939

Meetings: 2d Thursday of each month, 7:30 P.M., Wooten Hotel.

### CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

*President* - - - - - - - - Dale L. Benson
Sinclair Prairie Oil Company, Box 480
*Vice-President* - - - - Robert D. Hendrickson
Union Oil Company of California
*Secretary-Treasurer* - - - - - - - H. C. Cooke
c/o O. G. McClain, 224 Wilson Building

Regular luncheons, every Thursday, Terrace Annex Room, Robert Driscoll Hotel, 12:00. Special night meetings by announcement.

### DALLAS GEOLOGICAL SOCIETY
DALLAS, TEXAS

*President* - - - - - - Raymond A. Stehr
Seaboard Oil Company
1400 Continental Building
*Vice-President* - - - - - - - -John T. Rouse
Magnolia Petroleum Company
P.O. Box 900
*Secretary-Treasurer* - - - - - H. V. Tygrett
The Atlantic Refining Company
P.O. Box 2819
*Executive Committee* - - - - - Barney Fisher
Comanche Corporation
406 Continental Building

Meetings: Monthly luncheons and night meetings by announcement.

### EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

*President* - - - - - - - - P. S. Schoeneck
Atlantic Refining Company
205 Manziel Building
*Vice-President* - - - - - - - J. C. Price
Magnolia Petroleum Company
Box 780
*Secretary-Treasurer* - - - - - - G. C. Clark
Stanolind Oil and Gas Company
Box 660

Luncheons: Each week, Monday noon, Blackstone Hotel.
Evening meetings and programs will be announced. Visiting geologists and friends are welcome.

### FORT WORTH GEOLOGICAL SOCIETY
FORT WORTH, TEXAS

*President* - - - - - - - - R. H. Schweers
The Texas Company
Box 1720
*Vice-President* - - - - - - - F. H. Schouten
Stanolind Oil and Gas Company
Box 1410
*Secretary-Treasurer* - - - Millicent A. Renfro
Texas Pacific Coal and Oil Company, Box 2100

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

### HOUSTON GEOLOGICAL SOCIETY
HOUSTON, TEXAS

*President* - - - - - - - - A. F. Childers
Gulf Oil Corporation, Box 2100
*Vice-President* - - - - - Hershal C. Ferguson
Consultant, 935 Esperson Building
*Secretary* - - - - - - - - - R. R. Rieke
Schlumberger Well Surveying Corporation
*Treasurer* - - - - - - - Mary L. Holland
Stanolind Oil and Gas Company

Regular meeting held the second and fourth Mondays at noon (12 o'clock), Mezzanine floor, Rice Hotel. For any particulars pertaining to the meetings write or call the secretary.

## TEXAS

### NORTH TEXAS GEOLOGICAL SOCIETY
WICHITA FALLS, TEXAS

*President* - - - - - - - - - James F. Gibbs
Panhandle Refining Company, Panhandle Bldg.

*Vice-President* - - - - - - Leonard T. Teir
Anderson-Prichard Oil Corporation

*Secretary-Treasurer* - - - Joseph W. McDonald
Shell Oil Company, Inc., Box 2010, Radio Bldg.

Meetings: Luncheon 1st and 3d Wednesdays of each month, 12:00 noon, Y.W.C.A. Evening meetings by special announcement. Visiting geologists and friends are cordially invited to all meetings.

### SOUTH TEXAS SECTION AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

*President* - - - - - - - - Marion J. Moore
Sunray Oil Corporation
1610 Milam Building

*Vice-President* - - - - - - Paul B. Hinyard
Shell Oil Company
2000 Alamo National Building

*Secretary-Treasurer* - - - - Maurice E. Forney
Atlantic Refining Company
1728 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

### PANHANDLE GEOLOGICAL SOCIETY
AMARILLO, TEXAS

*President* - - - - - - - - Carlos M. Ferguson
Magnolia Petroleum Company, Box 1988

*Vice-President* - - - - - - - Robert J. Gutru
Cities Service Oil Company, Box 350

*Secretary-Treasurer* - - - - Fred S. Alexander
Standard Oil Company of Texas, Box 2087

Meetings: Luncheon 1st and 3rd Wednesdays of each month, 12:00 noon, Herring Hotel. Special night meetings by announcement.

### WEST TEXAS GEOLOGICAL SOCIETY
MIDLAND, TEXAS

President - - - - - - - - W. A. Waldschmidt
Argo Oil Corp., Box 1814

*Vice-President* - - - - - - - Sam C. Giesey
Union Oil Company of California

*Secretary* - - - - - - - - - Clyde W. Turner
Gulf Oil Corporation, Box 1150

*Treasurer* - - - - - - - - - Jane M. Johnson
Permian Basin Sample Laboratory, Box 1653

Meetings will be announced.

## WEST VIRGINIA

### THE APPALACHIAN GEOLOGICAL SOCIETY
CHARLESTON, WEST VIRGINIA
P.O. Box 2605

*President* - - - - - - - - Robert C. Lafferty
Consultant, 4007 Staunton Avenue, S.E.

*1st Vice-President* - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., 900 Union Building

*Secretary-Treasurer* - - - - Alan H. McClain
Owens, Libbey-Owens Gas Department, Box 4158

*Editor* - - - - - - - - - - R. Douglas Rogers
South Penn Natural Gas Company
Union Trust Building, Parkersburg, West Virginia

Meetings: Second Monday, each month, except June, July and August, at 6:30 P.M., Daniel Boone Hotel.

## WYOMING

### WYOMING GEOLOGICAL ASSOCIATION
CASPER, WYOMING
P.O. Box 545

*President* - - - - - - - - - Henry C. Rea
Consultant, Box 294

*1st Vice-President* - - - - - Victor H. King
General Petroleum Corporation
Box 1652

*2d Vice-President (Programs)* - - W. S. Knouse
Tide Water Assoc. Oil Company, Box 1708

*Secretary-Treasurer* - - - H. E. Summerford
Chemical Laboratories, Inc., Box 279

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special meetings by announcement.

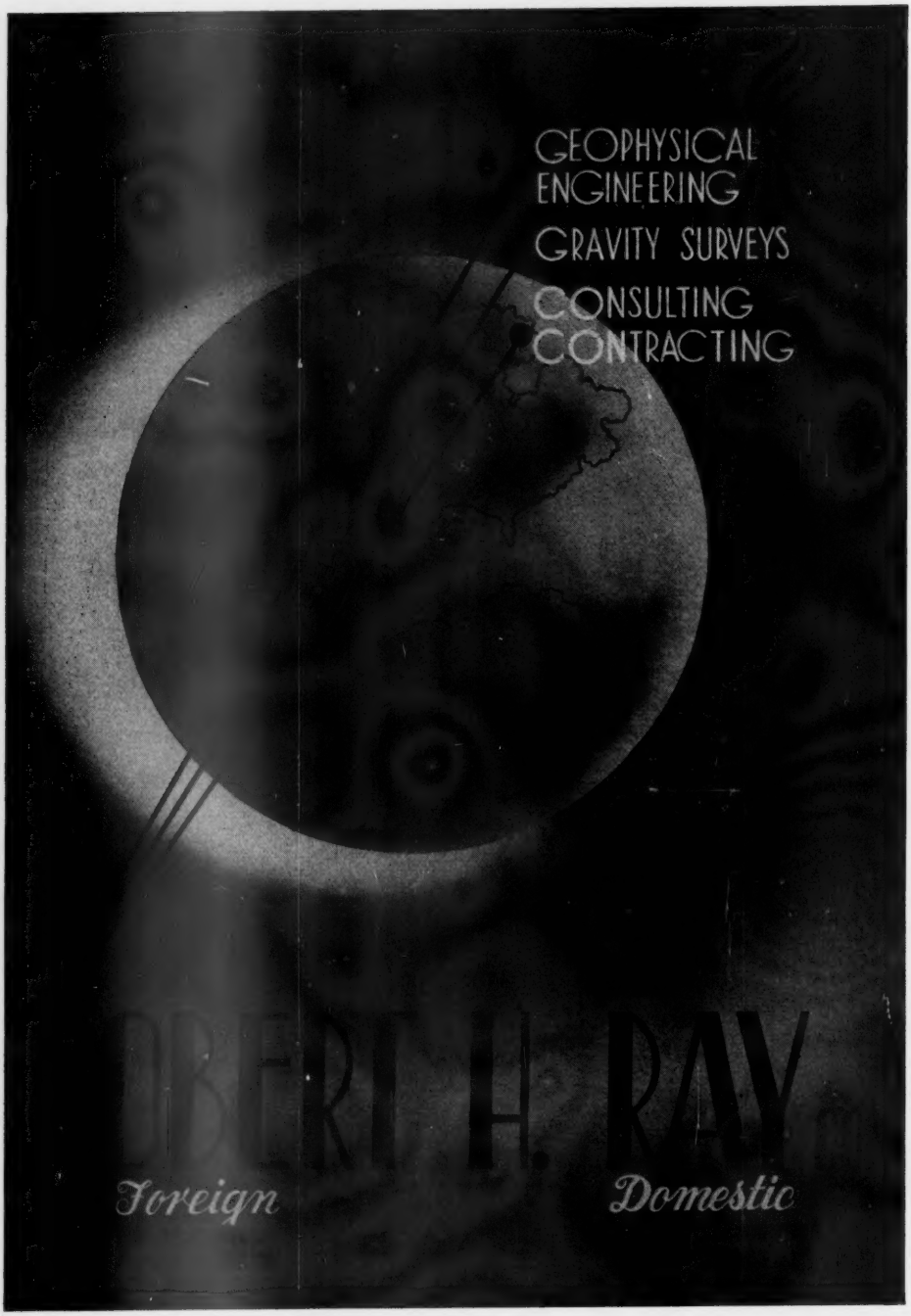

## POSSIBLE FUTURE OIL PROVINCES OF THE UNITED STATES AND CANADA

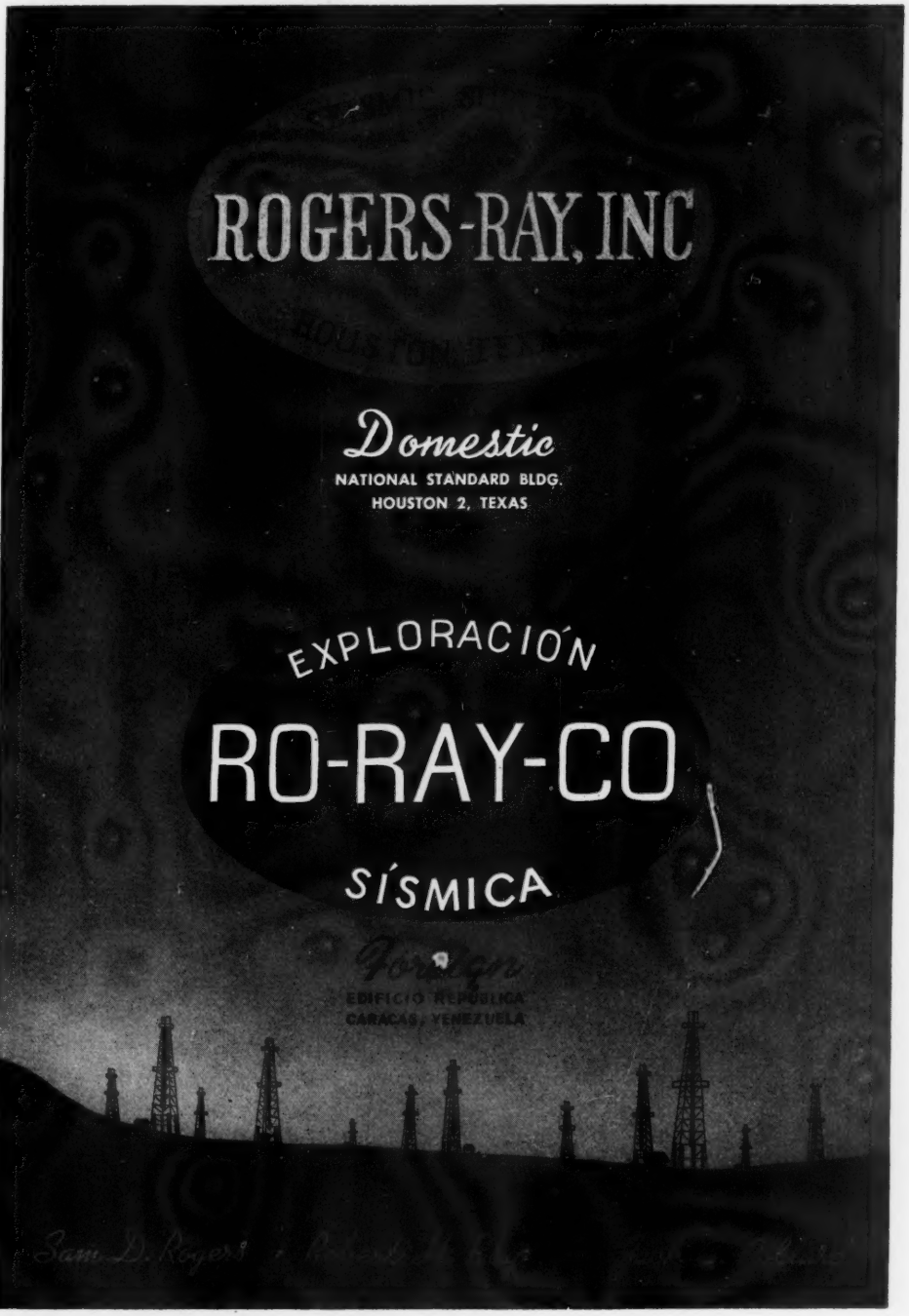
A symposium conducted by the Research Committee of The American Association of Petroleum Geologists, A. I. Levorsen, chairman. Papers read at the Twenty-sixth Annual Meeting of the Association, at Houston, Texas, April 1, 1941, and reprinted from the Association *Bulletin*, August, 1941.

Edited by A. I. LEVORSEN

154 pages, 83 illus. Price, $1.50, Postpaid
($1.00 to A.A.P.G. members and associate members)

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
Box 979, Tulsa 1, Oklahoma


GEOPHYSICAL
ENGINEERING
GRAVITY SURVEYS
CONSULTING
CONTRACTING
ROBERT H. RAY
Foreign
Domestic


ROGERS-RAY, INC
Domestic
NATIONAL STANDARD BLDG.
HOUSTON 2, TEXAS
EXPLORACIÓN
RO-RAY-CO
SÍSMICA
Foreign
EDIFICIO REPUBLICA
CARACAS, VENEZUELA

# FROST GEOPHYSICAL CORPORATION

*(Formerly C. H. Frost Gravimetric Surveys, Inc.)*

**AIRBORNE MAGNETOMETERS, For contract surveys, sale and lease.**

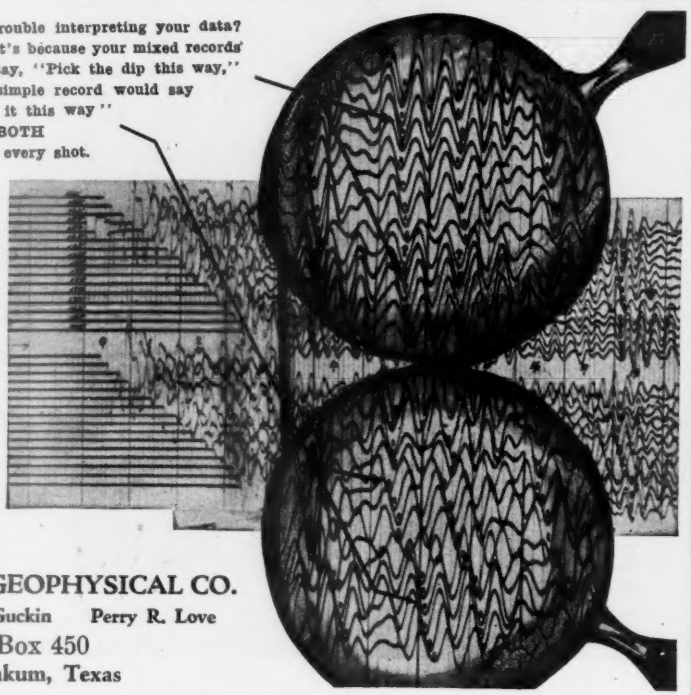
**GRAVIMETERS manufactured under license from Standard Oil Development Company.**

**GRAVIMETRIC AND MAGNETIC SURVEYS carefully conducted by competent personnel.**

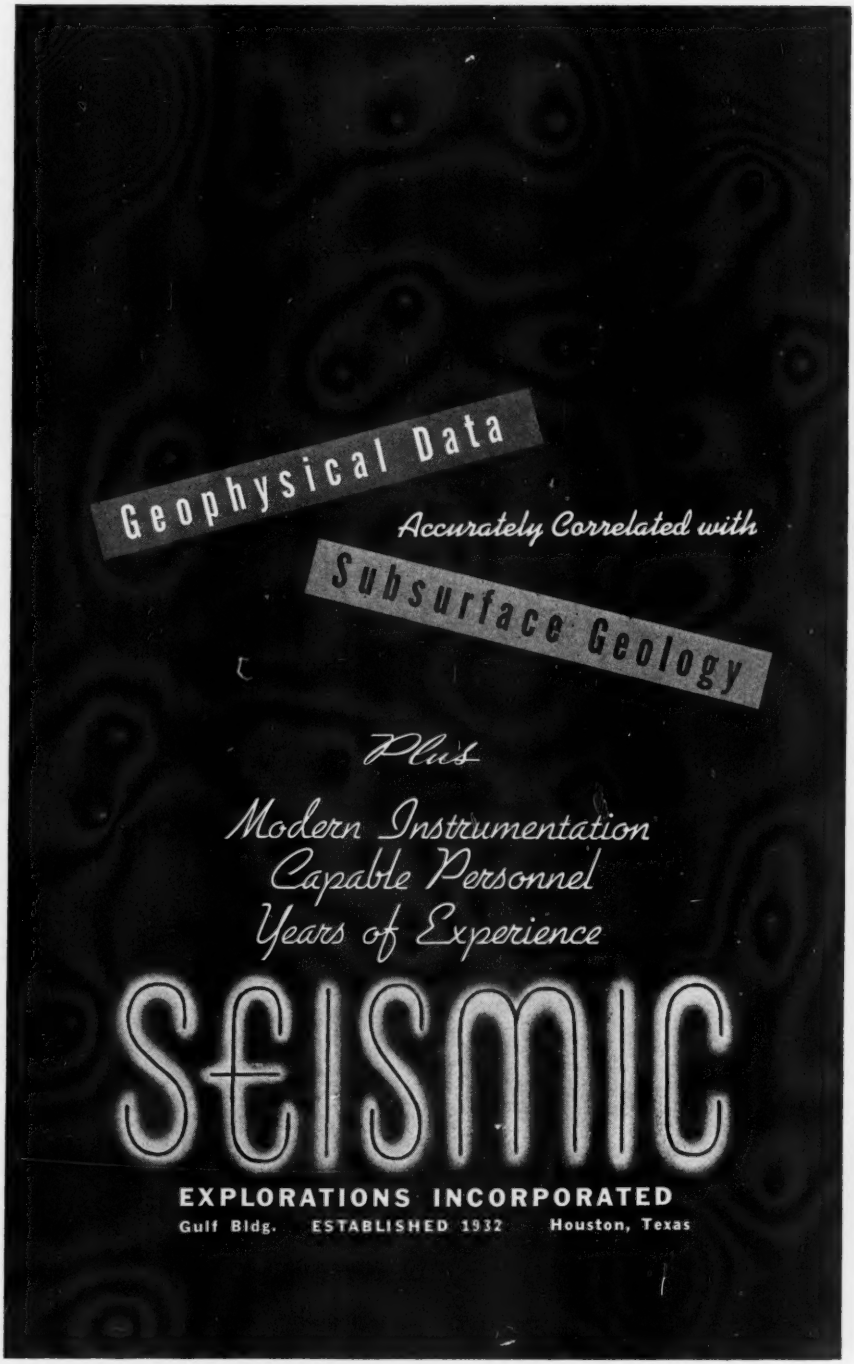
**GEOLOGIC INTERPRETATION of the results of gravimetric and magnetic surveys.**

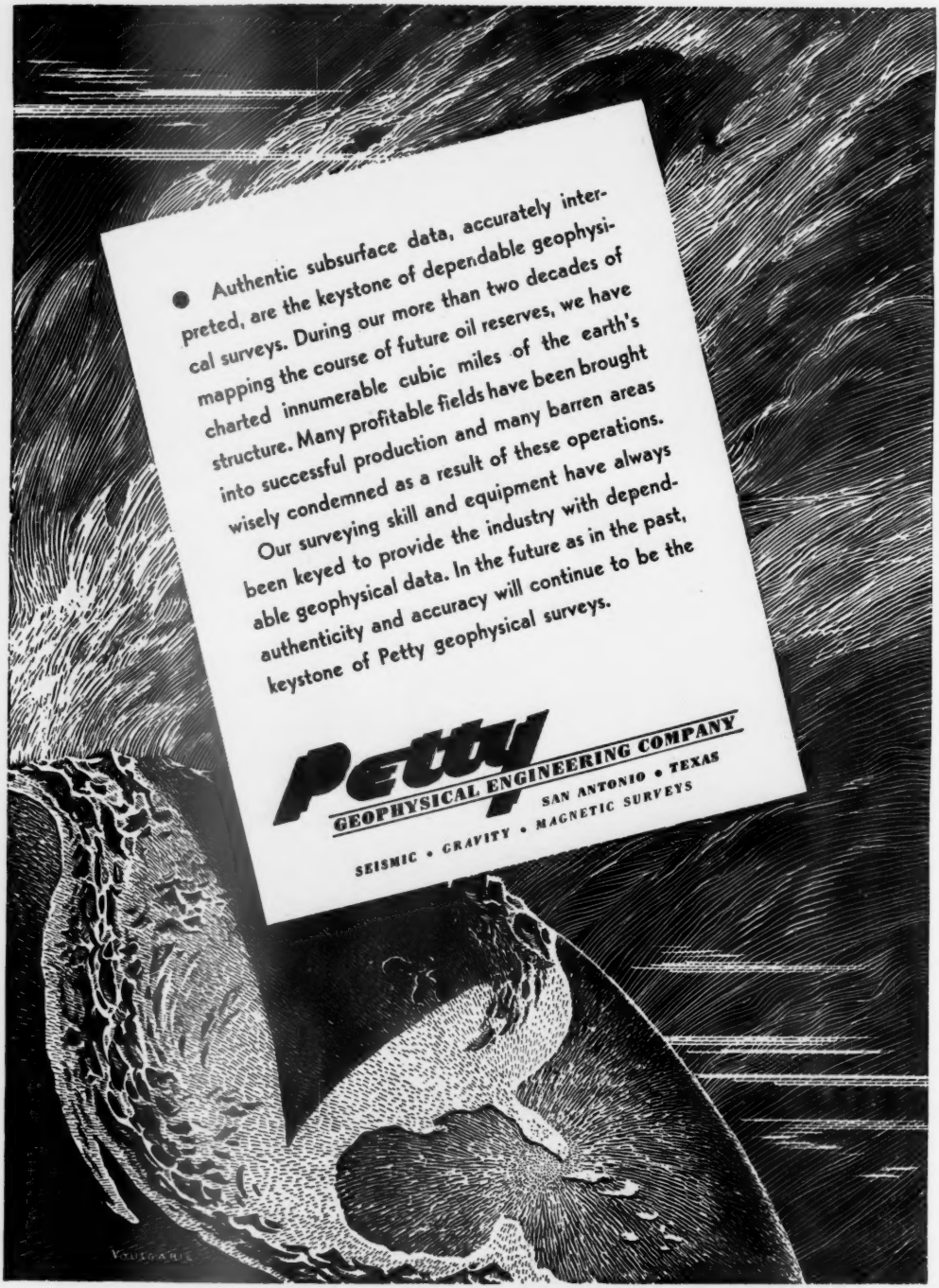
**4410 South Peoria Avenue** **Tulsa 3, Oklahoma**

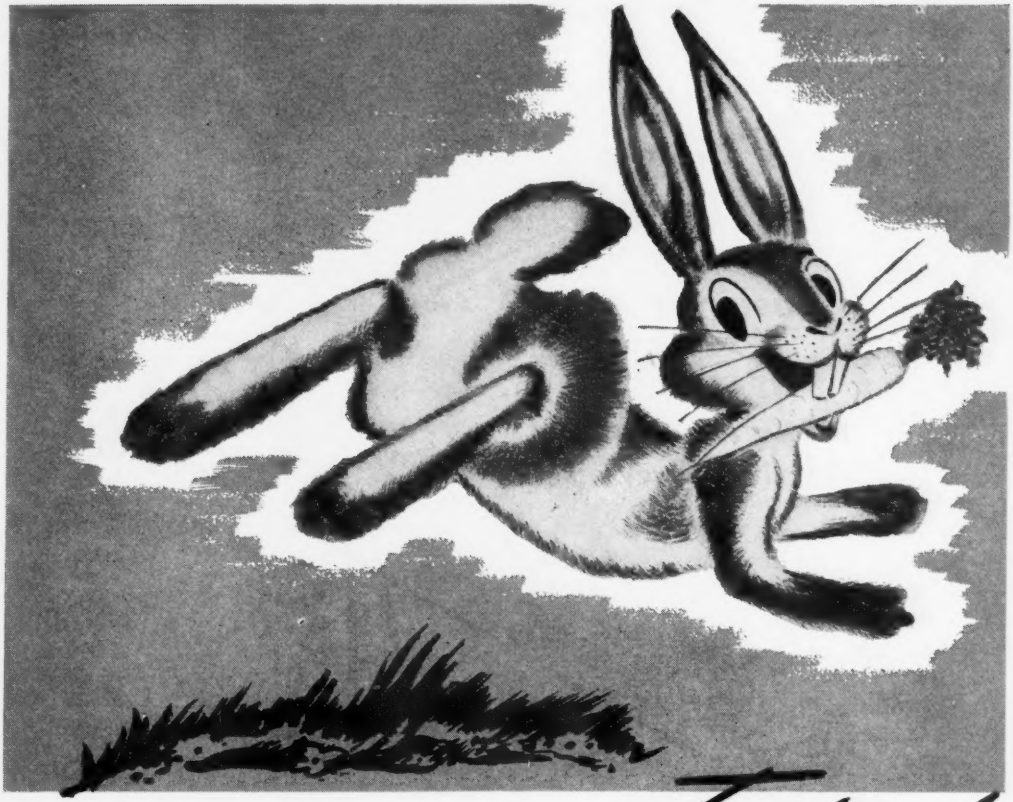
Having trouble interpreting your data?
Perhaps it's because your mixed records say, "Pick the dip this way,"
where a simple record would say
"Pick it this way"
**RELIABLE** gets **BOTH**
mixed and simple every shot.




**RELIABLE GEOPHYSICAL CO.**
Glenn M. McGuckin Perry R. Love
Box 450
Yoakum, Texas


Geophysical Data
Accurately Correlated with
Subsurface Geology
Plus
Modern Instrumentation
Capable Personnel
Years of Experience
SEISMIC
EXPLORATIONS INCORPORATED
Gulf Bldg. ESTABLISHED 1932 Houston, Texas


● Authentic subsurface data, accurately interpreted, are the keystone of dependable geophysical surveys. During our more than two decades of mapping the course of future oil reserves, we have charted innumerable cubic miles of the earth's structure. Many profitable fields have been brought into successful production and many barren areas wisely condemned as a result of these operations. Our surveying skill and equipment have always been keyed to provide the industry with dependable geophysical data. In the future as in the past, authenticity and accuracy will continue to be the keystone of Petty geophysical surveys.
Petty
GEOPHYSICAL ENGINEERING COMPANY
SAN ANTONIO • TEXAS
SEISMIC • GRAVITY • MAGNETIC SURVEYS



GET IN . . . GET OUT . . . *Faster!*

WITH BAROID DRILLING MUD PRODUCTS

*Production research reveals that damage to producing sands advances as the drilling-in time is increased. Though some delays are unavoidable, careful selection and control of drilling fluids reduce completion time and result in earlier and greater returns. For the best in mud control—always rely on Baroid Products. Used the world over to meet varying conditions and to provide faster, safer, more economical drilling.*

BAROID SALES DIVISION
NATIONAL LEAD COMPANY
LOS ANGELES 12 • TULSA 3 • HOUSTON 2

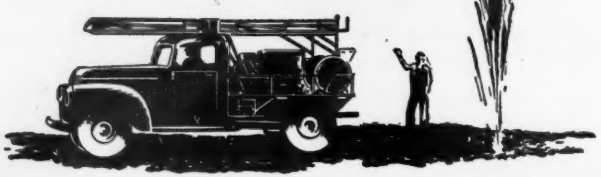
PATENT LICENSES, unrestricted as to sources of supply of materials, but on royalty bases, will be granted to responsible oil companies and others desiring to practice the subject matter of any and/or all of United States Patents Numbers, 2,041,086; 2,044,758; 2,064,936; 2,094,316; 2,119,829; 2,294,877; 2,387,674; 2,393,165; 2,393,173; 2,417,307 and further improvements thereof. Applications for licenses should be made to Los Angeles office.

General
GEOPHYSICAL COMPANY HOUSTON

ACCURATE
GEOPHYSICAL
SURVEYS

•

CORE DRILLING



*Our Business is*

# BOOMING

## LET *Century* GIVE YOU A PERFECT RECORD

There is over 100 years of geophysical experience represented in the technical staff of this company. This century of experience is available to you at Century Geophysical Corporation.

Century

**CENTURY GEOPHYSICAL CORP.**

TULSA, OKLAHOMA

NEW YORK
149 Broadway

HOUSTON
Niels-Esperson Building

Century

# PORTABLE SEISMIC EQUIPMENT

Designed by Century engineers to present to the industry completely portable seismic equipment with no sacrifice in operational quality or versatility because of portability.

Results are highly comparable to those obtained with the Century standard equipment and the same high quality of quality parts and workmanship are embodied in its construction.

Century Portable Equipment is available for 6, 12, 18, or 24 trace operation as combination reflection and refraction seismograph equipment. The complete unit consists of:

| | |
|---|---|
| Power Supply (with aircraft battery) | Shooting Equipment |
| Seismometers | Master Control and Test Unit |
| Daylight Developing Equipment | Reels |
| Amplifiers | Wire and Cable |

A. C. Elimination and Test Unit (Optional)

Rapidly spreading acclaim and many months of very successful field operations have shown this to be the most complete and practical portable unit in existence.

# CENTURY GEOPHYSICAL CORP.

## TULSA, OKLAHOMA

**NEW YORK**
**149 Broadway**

**HOUSTON**
**Niels-Esperson Bldg.**

# skillful execution means accurate aerial mapping

*These three Fairchild technicians are assembling prints of a recently completed aerial survey. These strips represent 60 mile flight paths. Note the exactness of the flight path . . . greatest variation was ⅛ mile from course.*

## . . . for better management and engineering

**MAPPING BY SPECIALISTS.** The Fairchild organization combines four professions. Engineering. Aviation. Photography. And photogrammetry... the science of photo-measuring. Good planning combined with excellent flight control methods, as exemplified by the flight patterns flown in the picture above, reflects the years of experience and technical ability of Fairchild men.

**FAIRCHILD'S RECORD.** Having undertaken projects throughout the world during the last twenty-five years, Fairchild engineers are highly qualified consultants for any type of survey involving aerial photography.

**WHEN PLANNING A SURVEY,** call in Fairchild engineers for your early conferences. Their assistance in the preliminary stages of planning is available to you at no obligation.

### *For Industry, Commerce and Public Works*

Since 1920, Fairchild has served clients the world over . . . conducting domestic and expeditionary aerial surveys in the fields of:

| | | |
|---|---|---|
| Petroleum | Highways | Taxation |
| Mining | Railroads | Harbors |
| Geology | Traffic | Flood Control |
| Forestry | Utilities | City Planning |
| Water Ways | Pipe Lines | Legal Evidence |

*Fairchild* **AERIAL SURVEYS, INC.**

*Photogrammetric Engineers*

224 E. 11th ST., LOS ANGELES 15, CALIF. • 21-21 FORTY-FIRST AVE., LONG ISLAND CITY 1, N. Y. • 73 TREMONT ST., BOSTON 8, MASS.

Want to Trade?

LANE-WELLS
RADIOACTIVITY
WELL LOGGING

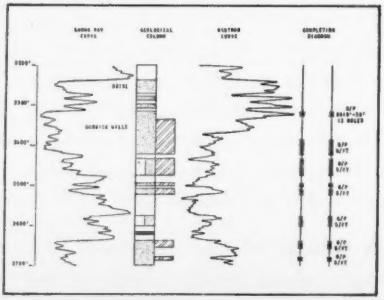
did just that for one operator!

HERE'S HOW

In this Oklahoma area, a large part of the production comes from a flank type "stratigraphic trap" structure with lenticular, usually very silty, sands.

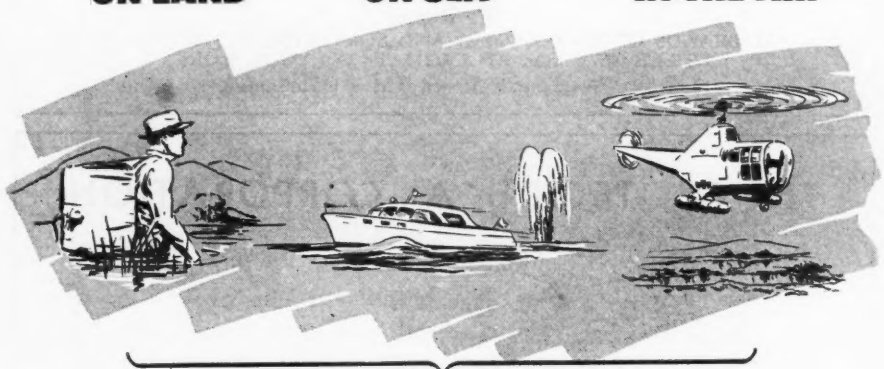
After setting 7" casing, this particular well was perforated with 12 holes between 3318' to 3328': it flowed 30,000,000 cu. ft. of dry gas before it was squeeze cemented. Then a Lane-Wells Combination Radioactivity Well Log was run.

Based on the Neutron Curve, the well was re-completed. New perforations were placed, 5 per foot opposite the sand zones from 3385' to 3700'. The well flowed 1500 BOPD; gas/oil ratio 600/1.



LANE WELLS COMPANY
LOS ANGELES • HOUSTON • OKLAHOMA CITY

**ON LAND** **ON SEA** **IN THE AIR**



# *Accurate Seismic Exploration*

Areas previously thought to be inaccessible for *seismic* operations . . . swamp, marsh and rugged mountainous areas, along with coastal waters . . . are now being economically and accurately surveyed by skilled Marine Exploration crews.

Marine crews are able to negotiate the difficult terrain due to the specially designed portable seismic equipment . . . employed by Marine Exploration and used *first* by Marine Exploration crews.

The compact portable mechanized drilling, shooting and surveying equipment has been designed by Marine for operation with the specialized electronic seismic instruments.

Marine Exploration crews have standardized on portable seismic equipment adaptable to land and water operations in any area.

Now, Marine crews have added helicopters as another means of quickly . . . and accurately . . . surveying difficult areas. With a maximum payload of only 400 lbs. any *complete Marine* unit may be transported and *operated* intact. In addition, Marine Exploration is equipped to compile data with conventional land seismic equipment.

Let Marine demonstrate the *economy* of using the *right* equipment in the *right* manner in your costly prospects.

Write us for complete information on how Marine Exploration can deliver to you accurate seismic surveys of any area you name. Crews are available for foreign and domestic work.

MARINE
EXPLORATION CO.

3732 WESTHEIMER ROAD JUSTIN 8-1521
HOUSTON 6, TEXAS

TRIANGLE BLUE PRINT & SUPPLY COMPANY
We Repair
ALL BRANDS OF MICROSCOPES AND SURVEYING INSTRUMENTS
LET US GIVE YOU AN ESTIMATE ON YOUR WORK
12 West Fourth Street, Tulsa, Oklahoma

THE GEOTECHNICAL CORPORATION

Roland F. Beers
President

P.O. Box 7166

D4-3947 Dallas, Texas

GEOPHYSICAL SURVEYS

UNIVERSAL EXPLORATION COMPANY

2044 Richmond Road

HOUSTON 6, TEXAS

TECTONIC MAP OF SOUTHERN CALIFORNIA
By R. D. Reed and J. S. Hollister
In 10 colors. From "Structural Evolution of Southern California," *BULL. A.A.P.G.* (Dec., 1936). Scale, ⅛ inch = 1 mile. Map and 4 structure sections on strong ledger paper, 27 x 31 inches, rolled in tube, postpaid, $0.50.
The American Association of Petroleum Geologists, Box 979, Tulsa 1, Oklahoma

MINERAL RESOURCES OF CHINA
By V. C. Juan
June-July, 1946 Issue, Part II, Economic Geology
75 cents per copy In lots of 10—$6.00
The Economic Geology Publishing Company
100 Natural Resources Building, Urbana, Illinois

# KEY TO FAST ACCURATE ELEVATIONS

In such diverse fields as geophysical prospecting, aerial mapping, reforestation projects, location surveys and construction work the W&T Sensitive Altimeter has proved its value as the key to fast, accurate elevation. Used in conjunction with the Two Base Method of Precise Altimetry actual experience has demonstrated that elevations can be established consistently to within 2 or 3 feet in approximately one tenth the time required by other methods.

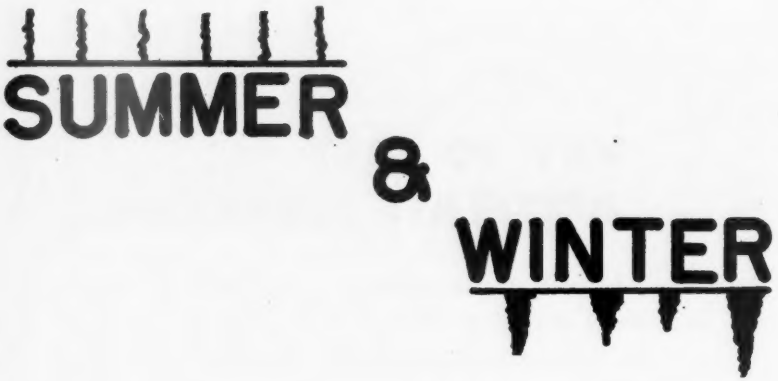
These are some of its outstanding features:

Accuracy . . . 1 part in 1000
Sensitivity . . 1 part in 8000
Ranges . . . . . 0-2000 feet
0-7000 feet
and 0-16,000 feet
Case . . . hardwood or metal

All types available in matched sets for ultra precision work. Write for technical literature.

A—68

**WALLACE & TIERNAN**
**PRODUCTS, INC.**
ELECTRICAL MECHANISMS AND PRECISION INSTRUMENTS
BELLEVILLE 9 NEW JERSEY




We have had over 12 continuous crew-years of gravimeter experience in the Rocky Mountain Area. It does not get too hot, too cold, nor too rough for our Personnel and Equipment to operate.

You are assured adequate station density as well as quality and quantity of data.

**STATES EXPLORATION COMPANY**

*Gravity Meter Surveys*

SHERMAN, TEXAS

# From the Arctic

# to the Tropics . . .

# GEOLOGRAPH

## MECHANICAL WELL LOGGING SERVICE

**IN the United States, the Geolograph is being used in the principal oil producing areas. Operators and Contractors, both large and small, are standardizing on this up-to-the-minute, streamlined service which insures them more footage and more information for every dollar spent in drilling.**

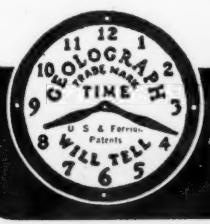
**Geolograph is being used in Mexico, Venezuela, Colombia, Peru and Argentina. Geolograph is out in front in the search for oil in Canada, where it is being used both in proven areas and on important exploratory tests.**

**During World War II, the Navy used the Geolograph in exploratory drilling in Petroleum Reserve No. 4, in Alaska. It is now being used by Arctic Contractors.**

**Rugged in construction, yet simple in design and readily portable, the Geolograph lends itself to foreign exploration. Geolograph Mechanical Well Logging Equipment is available on a rental basis. For service or further information contact your nearest representative.**

**District Offices: Shreveport, Louisiana . . . Odessa, Texas . . . Alice, Texas**

**General Offices: 27 N.E. 27 St., Oklahoma City . . . Phone 58-5511**




"TIME WILL TELL"

**THE GEOLOGRAPH CO. INC.**

P. O. Box 1291 Oklahoma City 1, Okla.

## PROOF OF BIT EFFICIENCY . . .

(NO. 2 OF A SERIES)

# EXPLORATION DRILL BIT COSTS *Reduced 50%*

Hawthorne Replaceable Blade Bits are easily serviced on the drill with tools commonly available. When assembled, the bit is a completely rigid unit that cannot loosen or "chatter" during drilling operations.

**Here's how a major seismograph operator saved $321.60 per month per drill in bit costs and drilled 33 1/3% more holes per month per drill with Hawthorne "Rock Cutter" Bits!**

A major seismograph operator, drilling in the same formation with the same drills and same drillers, kept an accurate record of bit performance and service costs for a six-month period. The first three-month period, an average of five roller bits and sixty conventional drag bits a month were used. Then he switched to Hawthorne "Rock Cutter" Bits. During this three-month period an average of two roller bits and only twelve sets of replaceable "Rock Cutter" blades were used—at a saving of $321.60 per month per drill in bit costs!

Even more remarkable was the increased footage obtained from each drill after "Rock Cutter" Bits were placed in service . . . average monthly footage per drill rose from 4200 feet to 5600 feet, or an increase of 33⅓% in the total number of holes completed each month!

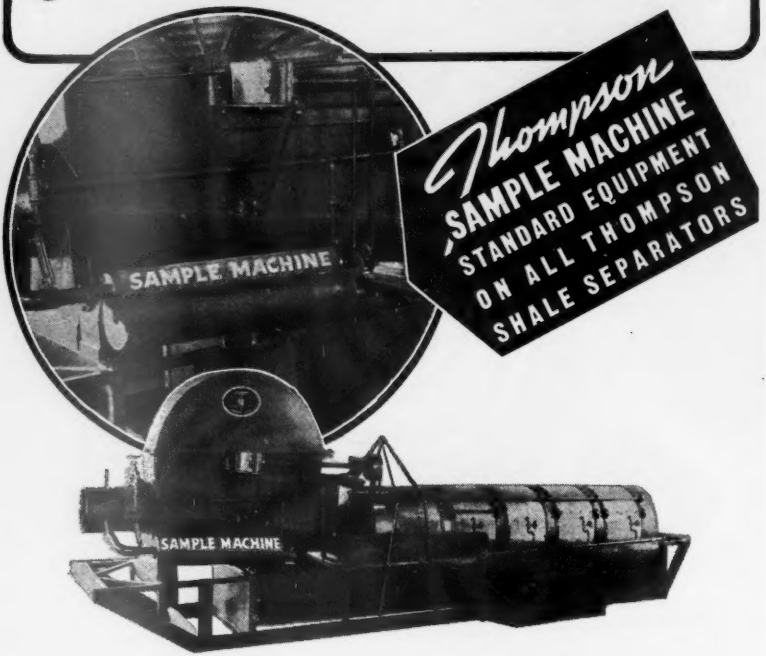
"Rock Cutter" Bits can bring the same economies with your present drills. Why not order a bit assembly and stock of blades today . . . they're available for immediate delivery, in all popular sizes for all types of drill rod. Complete details will be furnished upon request.

**HERB J. HAWTHORNE INC.**

P. O. BOX 7299 HOUSTON 8, TEXAS

Altimeters
for all preliminary surveys
How much money will this instrument save YOU? Preliminary surveys in 1/10th the time with accuracy better than 1 part in 1000.
Type SA-1: Range 4360' (-760' to + 3,600') in intervals of 2'
Type SA-2: Range 10600' (-900' to + 9,700') in intervals of 5'
Type SA-5: Range 15000' (-500' to + 14,500') in intervals of 10'
All models priced $200 complete with case, hand & shoulder straps, magnifier and thermometer. IMMEDIATE DELIVERY —see your dealer or write direct for descriptive folder.
AMERICAN PAULIN SYSTEM
Manufacturers of Precision Instruments
1847 SOUTH FLOWER STREET, LOS ANGELES 15, CALIFORNIA
Altimeters

# The Easiest . . . Quickest . . . and most Economical Way to get DEPENDABLE SAMPLES

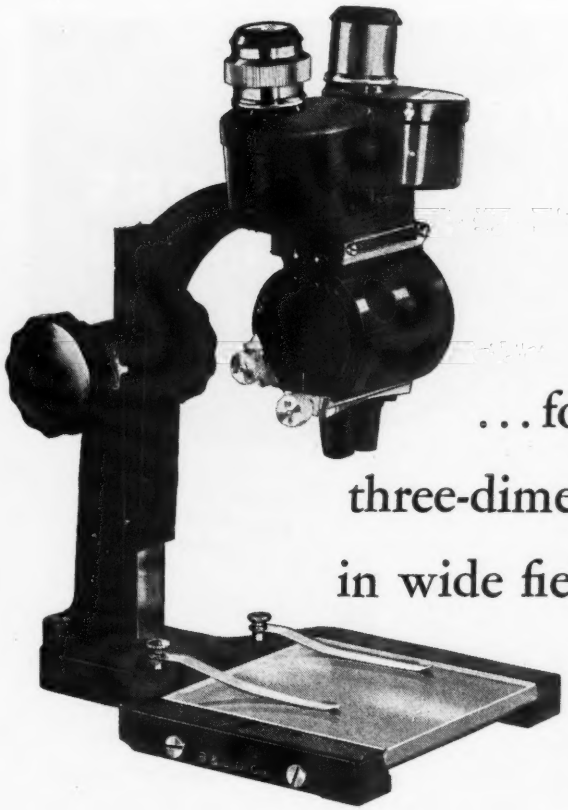



In addition to doing a thorough job of reconditioning drilling mud, the Thompson Shale Separator provides geologists with accurate foot by foot samples of cuttings and mud. By pushing a lever, part of the flow of mud is diverted into the Sample Machine. Here the mud is separated into . . . shale and abrasives . . . drilling mud . . . and deposited into two, easily accessible, catch basins. Many operators claim this alone is worth the entire cost of the Thompson Separator. Look for the Sample Machine on the Thompson Separator . . . it's the field-tested method of obtaining dependable samples.

## THOMPSON TOOL CO.

IOWA PARK, TEXAS

KEEPS DRILLING MUD CLEAN — PROVIDES TRUE SAMPLES OF CUTTINGS



# . . . for clear, sharp, three-dimensional vision in wide field microscopy

In examination of objects where magnification and depth perception are desirable, the Bausch & Lomb AKW Stereoscopic Wide Field Microscope is the ideal, convenient instrument.

It provides three-dimensional, erect unreversed images. It permits accurate examination of dissected specimens, textiles, machine parts, and extraneous material or parasite molds in dairy products, grain, plants, vegetables, and fruits.

The specimen may be placed on the large stage, or the microscope may be easily placed directly on the surfaces to be examined or built into inspection devices. Instantaneously variable magnification without refocusing, extremely wide field, and long working distances are a few of the other advantages of this instrument. Details are available in Catalog D-15. Bausch & Lomb Optical Company, 610-T St. Paul Street, Rochester 2, New York.

BAUSCH & LOMB

OPTICAL COMPANY ROCHESTER 2, N. Y.

# Attention

## CABLE TOOL OPERATORS

who are not personally acquainted with the

## BAKER CABLE TOOL CORE BARREL

. . . and how it secures accurate cores WHICH . . .

Eliminate danger of passing up productive sands

●

Make it possible to select proper casing locations

●

Offer positive proof of oil-bearing sands

●

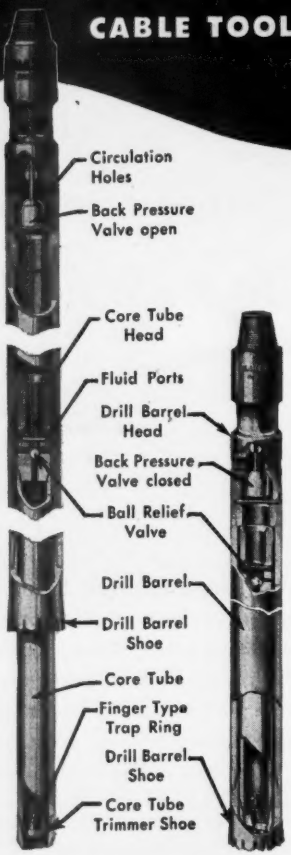
Permit study of character of formations

●

Are readily analyzed for porosity, permeability, etc.

●

Indicate any breaks in formation horizon




Takes good cores from wide range of formations

●

Cores are accurate, uncontaminated samples

●

Fast running time — coring as fast as drilling

●

Easy to run — any driller takes cores at once

●

Low-cost coring with minimum operating and upkeep expense

●

Long life — lasts indefinitely — few wearing parts

Contact BAKER OIL TOOLS, INC., Houston, Los Angeles, New York, or any BAKER Service Engineer for information about the . . .

## BAKER CABLE TOOL CORE BARREL

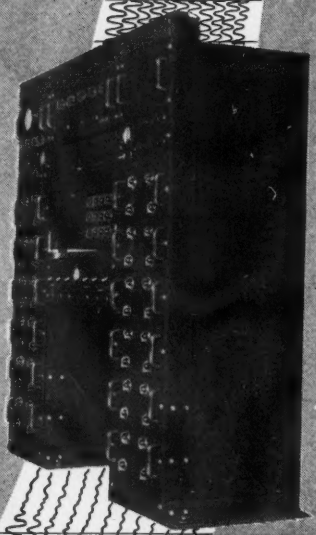
# LEDUC OIL FIELD

**Located With**

## HEILAND SEISMIC EQUIPMENT

• Outstanding among the oil discoveries made with Heiland Seismic Equipment during 1947 is Leduc Field in Alberta, Canada. In February, 1948, thirty-seven wells were producing 4,470 barrels of oil a day under government allowables.

Equipment used in locating this field was a complete rack mounted 24 trace Heiland Reflection Seismic Unit.



*Write today for complete information on this accurate, easy to use equipment.*

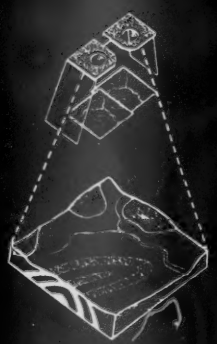
HEILAND
Denver

*dependable seismic equipment*

## New World-Wide Photogeological Analysis For Oil Exploration

*For accurate and rapid geologic evaluation at low unit area cost, more and more oil companies are using* GEOPHOTO *services as standard operating procedure.* GEOPHOTO *provides complete facilities for exploration programs on a world-wide scale.*

*For complete information write or wire to—*

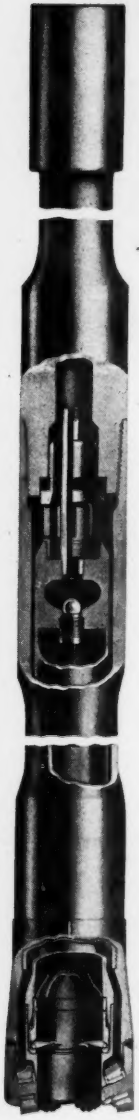


**GEOPHOTO SERVICES**

Cable Address: GEOPHOTO

305 ERNEST & CRANMER BLDG.
DENVER 2, COLORADO

# Here's a good way to select a core drill



**Run a comparative test. Compare the REED "Kor-King" with any other core drill and standardize on the one that gives the best results.**

Many of our best customers have standardized on REED "Kor-King" CORE DRILLS only after making careful performance comparisons. Their comparisons have shown to their complete satisfaction, that REED "Kor-Kings" consistently get a higher percentage recovery of good cores.

Other reasons for this preference are the long life and fast drilling action of Reed cutter heads, the simple, rugged construction of "Kor-King" core barrels, and the easily replaceable oil resistant core barrel bearings.

Use a Reed "Kor-King" on your next coring job. Keep records. Compare percentage recovery, core quality, and cutter head peformance. You will see for yourself why Reed "Kor-King" core drills are the preference of leading operators — all over the world.

**REED *Kor-King* CORE DRILL**

## REED ROLLER BIT COMPANY

P. O. BOX 2119 HOUSTON 1, TEXAS

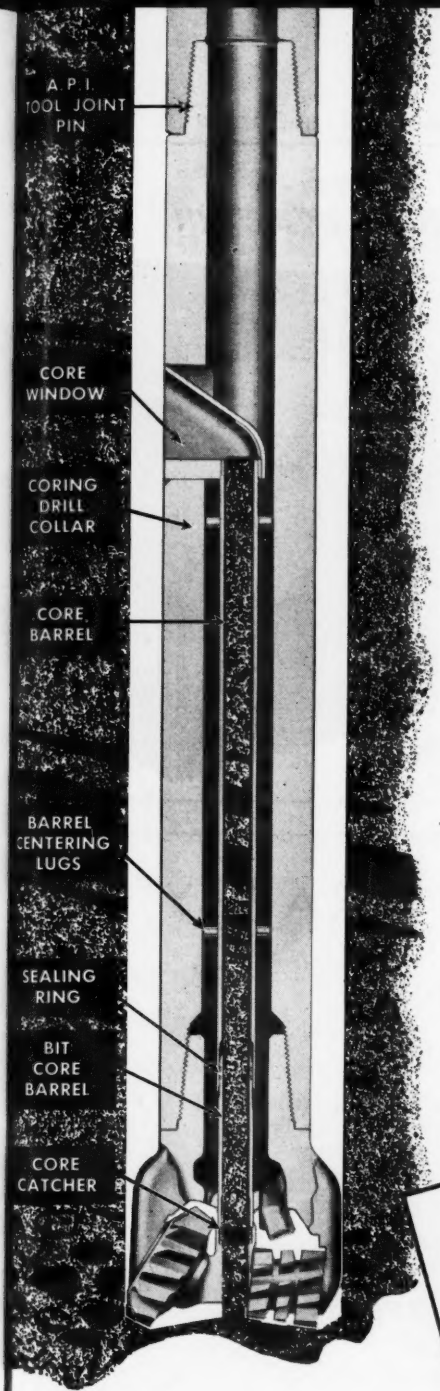
LONDON: 59 Wool Exchange, Coleman St., London E.C.2, England
NEW YORK: 1836 RCA Building, New York 20, New York
ARGENTINA: Avenida Presidente Roque, Saenz Pena 1124, Buenos Aires, Argentina

*Gulf Coast, Mid-Continent and Rocky Mountain Distributor for Martin-Decker Products*

Write Your Own Chapter in This Great Oil Story
HOW 34,000 OIL COMPANIES SERVE THE NATION...
THE BIGGEST JOB THIS JOBBER EVER DID
Keeping Your Community Supplied with Oil
OIL INDUSTRY INFORMATION COMMITTEE
670 Fifth Avenue, New York 19, N. Y.

• **Send for NEW '48 Tie-in Supplement Now.** To help you tie-in and benefit locally from this extensive national advertising campaign, a new Tie-in Supplement has been prepared for your use.

It offers FREE mats of new campaigns that tell your story, plus free radio scripts and recordings, promotion aids and special material for special groups, which can be used very profitably by your firm. Send for your '48 Supplement now! Write to: Oil Industry Information Committee, Dept. 1L, 670 Fifth Avenue, New York 19, N.Y.




**SAME ROCK BIT FOOTAGE AND A CORE SAMPLE ANY TIME YOU WANT IT**

# The Security CORING BIT

TRADE MARK

## SATISFIES BOTH GEOLOGISTS AND DRILLERS

THE SECURITY CORING BIT used in place of conventional rock bits gives comparable footage at same drilling speeds but *produces a perfect core of the last three feet of hole drilled.* No drilling time is lost. Your core is ready at any time you want it and a record of formation changes automatically produced for the geologist without extra effort.

## HOW THE SECURITY CORE BIT WORKS

The core barrel is centered in the coring drill collar and supported above by the enclosed core breaker cage. As the core reaches the top of the barrel, it is broken into small fragments and deflected outwardly through a window into the mud stream. Drilling speed and footage are in no way impeded by continuous coring. When the bit is withdrawn, the last 3 feet of core produced is retained in the barrel and is available for immediate inspection.

**SECURITY CORE BITS** are available in popular rock bit sizes at all Security warehouses and branch offices. Detailed information is available on request.

Security
DRILLING AND PRODUCTION EQUIPMENT

**SECURITY ENGINEERING CO., INC.**
ONE OF THE DRESSER INDUSTRIES
MAIN OFFICE AND PLANTS: WHITTIER, CALIFORNIA
EXPORT OFFICE: SUITE 800, CHANIN BUILDING, 122 EAST 42ND STREET, NEW YORK 17, NEW YORK
BRANCHES IN ALL PRINCIPAL OIL FIELDS

## *Announcing Our New 1948 Design . . .*

## "THE LUSTROUS SEVEN STAR BEAUTY"

*World's Best Map Filing Cabinet*

*CONVENIENT *INSTANT REFERENCE *SPACE SAVER
*INSTANT FILING *DUST PROOF *RUST PROOF
*MEDDLER PROOF

**CAPACITY: 60—75—100—160—200**

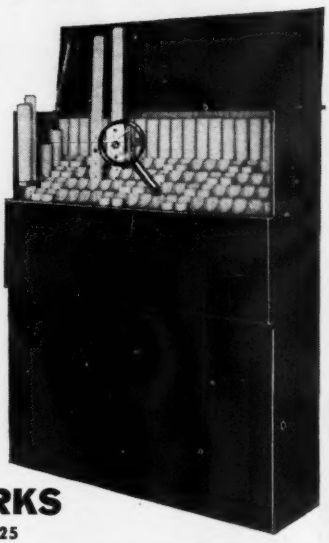
Ultra Attractive—fits the furniture scheme of any office.

Instant Adjustment—for maps or tracings from 12" to 54" long. Each well 2" x 2", equipped with individual wood slide with holes on 2" centers, through which one screw when matched to hole in adjustment block and tightened, automatically gives perfect alignment at top for all length maps. Substantial lock —Individually keyed.

Exterior of cabinet made of ¾" five ply beautiful grained hardwood mitered locked joints, banded edges on door and top. Interior partitions ⅜" thick, and ¼" slides, all three ply veneer of southern hardwood or fir.

Finished: Walnut, Oak, Mahogany, Olive Drab Green, Natural or Blond. Other type cabinets designed to suit your needs. Information on request.

*We specialize in Drafting Tables and Light Tables made to your order.*



## PORT CITY CABINET WORKS

609-13 Quitman St., HOUSTON 9, TEXAS Phone P-0725



# MIOCENE STRATIGRAPHY OF CALIFORNIA

*By ROBERT M. KLEINPELL*

This Work Establishes a Standard Chronologic-Biostratigraphic Section for the Miocene of California and Compares It with the Typical Stratigraphic Sequence of the Tertiary of Europe

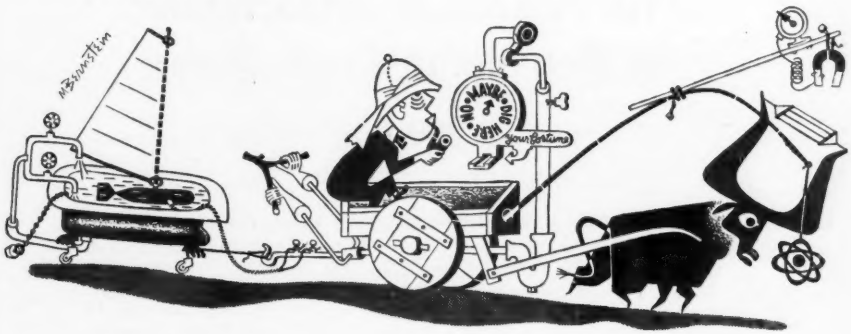
450 pages; 14 line drawings, including a large correlation chart in pocket; 22 full-tone plates of Foraminifera; 18 tables (check lists, and a range chart of 15 pages). Bound in blue cloth; gold stamped; paper jacket: 6 x 9 inches.

*"One must admire the painstaking determination with which so many successive associations of Foraminifera were collected, identified and tabulated. Such labour would scarcely have been thought of without the stimulus which the search for oil has given to the detailed study of Foraminifera.*
*"This should be standard work on the Miocene of California for years to come."*
*A.M.D. in "Nature," Vol. 144 (London, December 23, 1939), p. 1030.*

PRICE: $5.00, POSTPAID
($4.50 TO A.A.P.G. MEMBERS AND ASSOCIATES)

The American Association of Petroleum Geologists
BOX 979, TULSA 1, OKLAHOMA, U.S.A.

# Sure You Can!



*Probably you can think up rigs even fancier than this for the modern, continuous-trace magnetometer.*

But! If you want precise magnetic maps . . . made the fastest, most efficient way . . . using methods proved on a quarter million miles of airborne magnetometer surveys . . . . .

have **AERO** make your surveys . . .

**AERO SERVICE CORPORATION**

*VIRGIL KAUFFMAN, President*

236 E. COURTLAND STREET, PHILADELPHIA 20, PA.

AERIAL PHOTOGRAPHY • COLOR PHOTOGRAPHY • PRECISE AERIAL MOSAICS • AIRBORNE MAGNETOMETER SURVEYS • PLANIMETRIC MAPS • TOPOGRAPHIC MAPS • RELIEF MODELS

*Licensed by Gulf Research and Development Company*

AVAILABLE PUBLICATIONS OF

# The American Association of Petroleum Geologists

**Box 979, Tulsa 1, Oklahoma**

---

1931 **Geologic Map of Cuba.** Compiled by J. Whitney Lewis. Folded paper sheet, 24 x 10 inches. Scale, 3/16 inch = 10 miles. Geologic column on same sheet. From Lewis' "Geology of Cuba," in June, 1932, *Bulletin* ..... $ .25

1936 **Geology of the Tampico Region, Mexico.** By John M. Muir. 280 pp., 15 half-tone plates, 41 line drawings, 9 tables. 6 x 9 inches. Cloth. **To members and associates, $3.50** ..... 4.50

1936 **Areal and Tectonic Map of Southern California.** By R. D. Reed and J. S. Hollister. In 10 colors. From "Structural Evolution of Southern California," December, 1936, *Bulletin.* Scale, ⅛ inch = 1 mile. Map and 4 structure sections on strong ledger paper, 27 x 31 inches, rolled in tube .50

1938 **Miocene Stratigraphy of California.** By Robert M. Kleinpell. 450 pp.; 14 line drawings, including a large correlation chart; 22 full-tone plates of foraminifera; 18 tables (check lists and a range chart of 15 pages). 6 x 9 inches. Cloth. **To members and associates, $4.50** ..... 5.00

1946 **Directory of Geological Material in North America.** By J. V. Howell and A. I. Levorsen. 112 pp. From Part II of August, 1946, *Bulletin.* 6.75 x 9.5 inches. Paper ..... .75

1947 **Possible Future Oil Provinces of the United States and Canada. Third printing.** From August, 1941, *Bulletin.* 154 pp., 83 figs. 6 x 9 inches. Paper. **To members and associates, $1.00** ..... 1.50

1947 **Tectonic Map of the United States.** Second printing. Originally published, 1944. Prepared under the direction of the Committee on Tectonics, Division of Geology and Geography, National Research Council. Scale, 1 inch = 40 miles. Printed in 7 colors on 2 sheets, each 40 x 50 inches. Folded, $1.75. Rolled in tube ..... 2.00

1947 **Comprehensive Index of the Publications of the A.A.P.G., 1917-1945.** Compiled by Daisy Winifred Heath. 603 pp. 6.75 x 9.50 inches. Cloth. **To members and associates, $3.00** ..... 4.00

1948 **Structure of Typical American Oil Fields.** Vol. III. McCoy Memorial Volume. 24 papers. 516 pp. 219 illus. Cloth. **To members and associates, $3.50** . 4.50

**Bulletin of The American Association of Petroleum Geologists.** Official monthly publication. Each number, approximately 150 pages of articles, maps, discussions, reviews. Annual subscription, $15.00 (outside United States, $15.40). Descriptive price list of back numbers on request.

**(Prices, postpaid. Write for discount to colleges and public libraries.)**

***Alexander Watts McCoy Memorial Volume***

# STRUCTURE OF TYPICAL AMERICAN OIL FIELDS

## A SYMPOSIUM ON THE RELATION OF OIL ACCUMULATION TO STRUCTURE

VOLUME III BY MANY AUTHORS EDITED BY J. V. HOWELL

This is the newest (1948) book in the Structure Series. It contains descriptions of oil and gas fields characterized by distinctive and peculiar features of stratigraphy, structure, and accumulation.

CONTENTS


| | | Page |
|---|---|---|
| ALABAMA: | Gilbertown, by A. M. Current | 1 |
| ARKANSAS: | Fouke, by C. B. Schwartz | 5 |
| CALIFORNIA: | Aliso Canyon, by Claude E. Leach | 24 |
| | Cymric, by J. H. McMasters | 38 |
| | Edison, by J. H. Beach | 58 |
| CANADA: | Norman Wells, by J. S. Stewart | 86 |
| COLORADO: | Gramp's, by W. A. Waldschmidt | 110 |
| | Rangely, by W. Y. Pickering and C. L. Dorn | 132 |
| ILLINOIS: | Marine, by Heinz A. Lowenstam | 153 |
| | Omaha, by R. M. English and R. M. Grogan | 189 |
| KANSAS: | Augusta, by George F. Berry, Jr., and Paul F. Harper | 213 |
| | Geneseo Uplift, by Stuart K. Clark, C. L. Arnett, and James S. Royds | 225 |
| | Kraft-Prusa, by Robert F. Walters and Arthur S. Price | 249 |
| LOUISIANA: | Creole, by Theron Wasson | 281 |
| MICHIGAN: | Deep River, by Kenneth K. Landes | 299 |
| | Deerfield, by George D. Lindberg | 305 |
| OKLAHOMA: | Arcadia-Coon Creek, by George E. Carver, Jr. | 319 |
| | Cumberland, by Ira H. Cram | 341 |
| | West Edmond, by Robert Malcolm Swesnik | 359 |
| TEXAS: | Apco, by Samuel P. Ellison, Jr. | 399 |
| | Quitman, by E. R. Scott | 419 |
| | Talco, by E. A. Wendlandt and T. H. Shelby, Jr. | 432 |
| VIRGINIA: | Rose Hill, by Ralph L. Miller | 452 |
| WYOMING: | Steamboat Butte, by H. E. Barton | 480 |
| INDEX | | 515 |


● 516 pages. 219 illus. Clothbound. 6 x 9 inches

**Prices, Postpaid**

**Members, $3.50 Non-Members, $4.50**

**THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS**

**Box 979, TULSA 1, OKLAHOMA**

# Western

SERVES

**COAST TO COAST**

**BORDER TO BORDER**

*This map indicates the number and type of Western crews which operated in each State during 1947.*

**KEY**

- Seismic Survey Parties
- Gravity Meter Survey Parties
- Core Drill & Electric Logging Parties
- Elevation Meter Survey Parties
- Main Office and Plant
- Division Headquarters

**WESTERN MANUFACTURES FOR SALE OR RENTAL—**

*Seismic Instruments and Equipment • Gravity Meters • Elevation Meters • Electrical Logging Units • Portable Shot Hole and Core Drilling Rigs*

*Western's* activities since the inception of the company in 1933 include operations in every major producing and potential petroleum producing province in the United States. This wide experience, solving all types of geophysical problems, together with superior personnel, equipment and research facilities enables *Western* to meet every requirement of operators desiring the most complete and highly advanced geophysical service.

The accuracy of its surveys is attested by its numerous clients and by the many discovery wells which have been located on the basis of Western surveys.

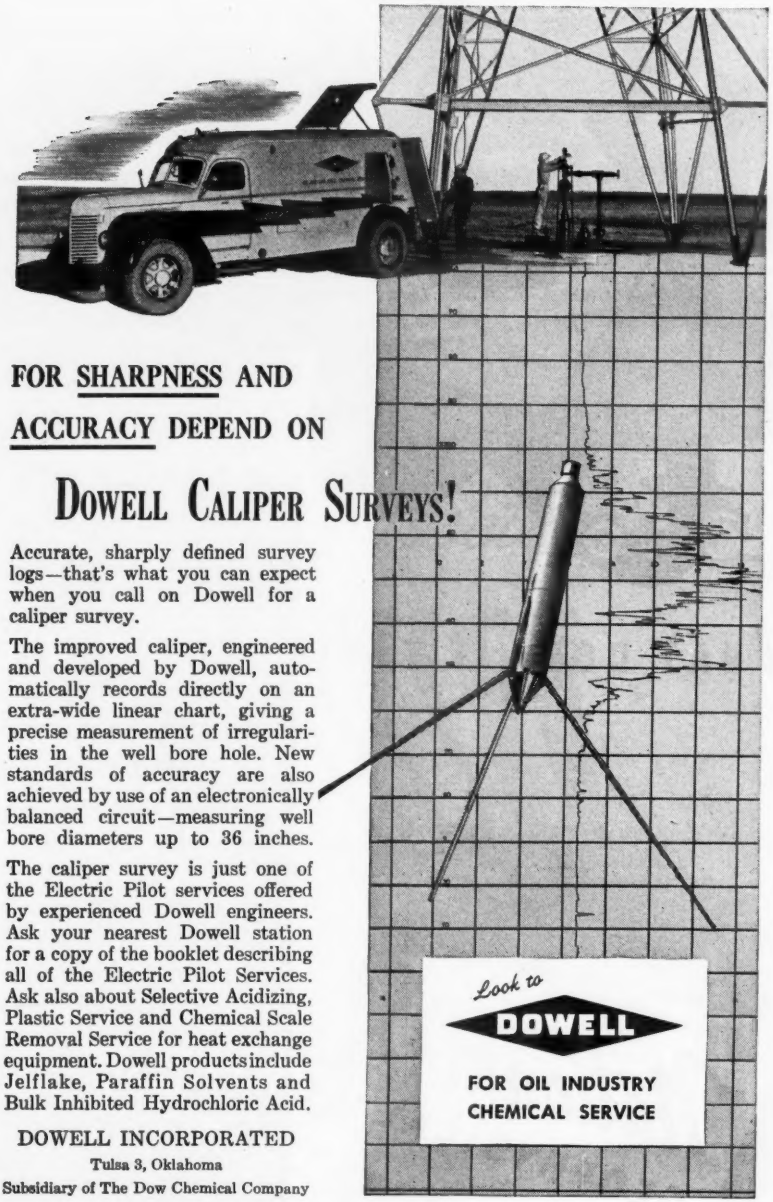
In addition to the domestic operations depicted, Western field parties, equipment and/or instruments are now operating in Paraguay, Argentina, Australia, Ethiopia, Italy, France and China. *Western services are available in any part of the world.*

# Western GEOPHYSICAL COMPANY

HENRY SALVATORI, PRESIDENT

EDISON BUILDING, LOS ANGELES 13, CALIFORNIA, U.S.A.

DOMESTIC DIVISION HEADQUARTERS—DALLAS, TEXAS • CASPER, WYOMING • NATCHEZ, MISS. • TULSA, OKLA.



FOR SHARPNESS AND ACCURACY DEPEND ON

DOWELL CALIPER SURVEYS!

Accurate, sharply defined survey logs—that's what you can expect when you call on Dowell for a caliper survey.

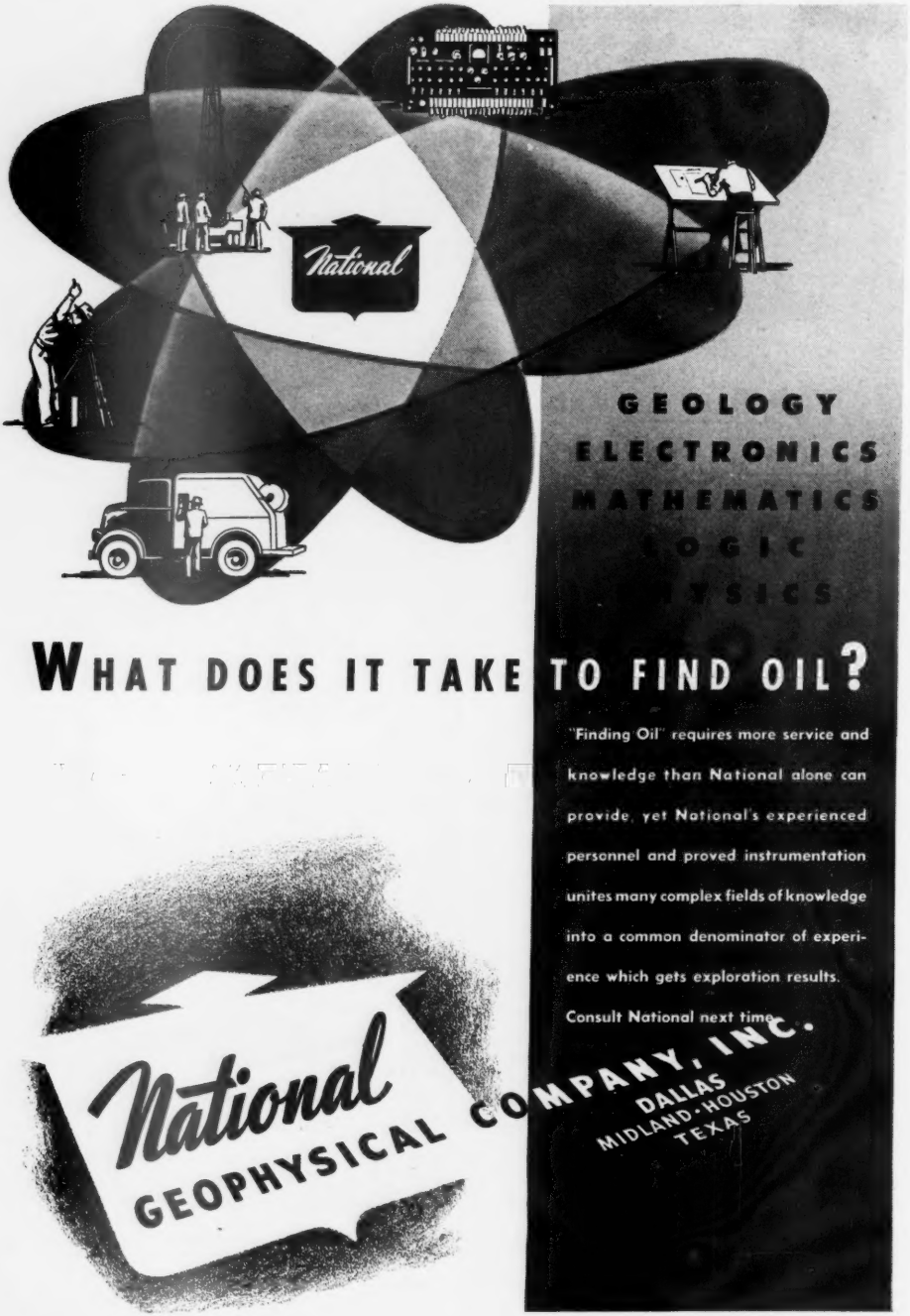
The improved caliper, engineered and developed by Dowell, automatically records directly on an extra-wide linear chart, giving a precise measurement of irregularities in the well bore hole. New standards of accuracy are also achieved by use of an electronically balanced circuit—measuring well bore diameters up to 36 inches.

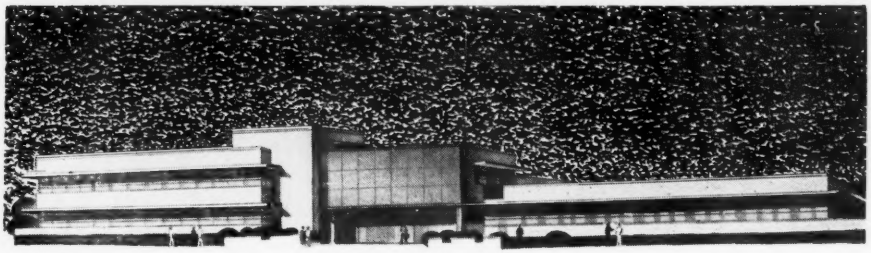
The caliper survey is just one of the Electric Pilot services offered by experienced Dowell engineers. Ask your nearest Dowell station for a copy of the booklet describing all of the Electric Pilot Services. Ask also about Selective Acidizing, Plastic Service and Chemical Scale Removal Service for heat exchange equipment. Dowell products include Jelflake, Paraffin Solvents and Bulk Inhibited Hydrochloric Acid.

DOWELL INCORPORATED
Tulsa 3, Oklahoma
Subsidiary of The Dow Chemical Company

Look to DOWELL
FOR OIL INDUSTRY CHEMICAL SERVICE

*"Petroleum Promotes Progress"*


National
GEOLOGY
ELECTRONICS
MATHEMATICS
LOGIC
PHYSICS
WHAT DOES IT TAKE TO FIND OIL?
"Finding Oil" requires more service and knowledge than National alone can provide, yet National's experienced personnel and proved instrumentation unites many complex fields of knowledge into a common denominator of experience which gets exploration results.
Consult National next time.
National
GEOPHYSICAL COMPANY, INC.
DALLAS
MIDLAND-HOUSTON
TEXAS



The new G S I home at 6000 Lemmon Avenue, Dallas . . . 40,000 square feet of plant on seven acres . . . housing the most modern facilities for engineering, research and crew maintenance. We invite you to visit us.

*Built for Better*

**SERVICE**

**GEOPHYSICAL SERVICE INC.**

SEISMIC SURVEYS

6000 LEMMON AVENUE DALLAS, TEXAS

"FOR FULL UNCONTAMINATED CORES YOU CAN DEPEND ON A HUGHES CORE BIT"

HUGHES TOOL COMPANY HOUSTON, TEXAS

*Standard of the Industry*